PREDICTION OF LONG-TERM STRESS RANGES

Study Report

J.W. Fothergill, H.Y. Lee, and P.A. Fothergill

37

June 1973

Final Report

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22151

Prepared for

FEDERAL HIGHWAY ADMINISTRATION

Offices of Research & Development

Washington, D.C. 20590

NOTICE

TE 662 .A3 no. FHWA-RD-73-42

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-RD-73-42		

4. Title and Subtitle	5. Report Date
PREDICTION OF LONG-TERM STRESS RANGES Study Report	June, 1973
	6. Performing Organization Code
7. Author(s) J. W. Fothergill, H. Y. Lee, and P. A. Fothergill	8. Performing Organization Report No.
9. Performing Organization Name and Address Integrated Systems, Inc. 6900 Wisconsin Avenue Chevy Chase, Maryland 20015	10. Work Unit No. FCP 35G1-012
	11. Contract or Grant No. DOT-FH-11-7904
12. Sponsoring Agency Name and Address Offices of Research and Development Federal Highway Administration U.S. Department of Transportation Washington, D.C. 20590	13. Type of Report and Period Covered Final Report
	14. Sponsoring Agency Code SØ231

15. Supplementary Notes

FHWA contract manager: W. L. Armstrong (HRS-11)

16. Abstract

General: The development of a computer simulation program system for generating highway traffic crossing a bridge and calculating the resulting stresses and stress ranges is described. The total system consists of four stand-alone programs which can be used either independently or as a dependent series where output from one program is used as input to the next. Output consists of loading and stress range histograms.

Report 73-42: A summary of all work performed and a descirption of each of the developed computer programs is presented. Included is a discussion on methods employed in the development including the stress calculations, the traffic generator, the preparation of stress histograms, results of a sensitivity or parameter study, and deficiencies in the methods of analysis. Comparisons of predicted and experimentally measured results are given.

This report is the first in a series. The others in the series are:

FHWA No.	Short Title
FHWA-RD-73-43	Users Manual - Bridge Load Generator
FHWA-RD-73-44	Users Manual - Bridge Dynamic Stress Analysis
FHWA-RD-73-45	Users Manual - Stress Histogram Prediction System

17. Key Words	18. Distribution Statement
bridges, stress history, traffic simulation, stress range, and fatigue	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22151.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	288	

Form DOT F 1700.7 (8-69)

PREFACE

This project was a continuation of work performed by Kelly Scientific Corporation on Forecasting of Heavy Loading Patterns on Highway Bridges (1). The computer simulation program (BRIGLD1) developed in that work and as modified by Messrs. William Armstrong and S. Smith of the Federal Highway Administration Research Laboratory, was the starting point for the work described in this report.

The cooperation of Dr. Conrad Heins of the University of Maryland in furnishing strain gage recordings and correlated truck data on bridges in Maryland is gratefully acknowledged.

Without the wholehearted and conscientious support of Mr. William Armstrong, the Contract Manager, and Mr. T. Godbout, the Contract Administrator of the Federal Highway Administration, the quantity and quality of the work performed could not have been achieved within project constraints.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
BACKGROUND	5
Task I - Sensitivity Analysis	7
Task II - Extend model to Stress Calculations	7
Task III - Prepare Stress Histograms/Tables	9
Task IV - Extend the Analytical Approach	10
Deficiencies in the BRIGLD1 Simulator	10
DESCRIPTION OF WORK ON BRIGLD1 SIMULATOR	12
Program Errors	17
User Data Input	20
Traffic Generation	21
Vehicle Data Buffer Handling	22
Vehicle Motion	29
Statistical Output	30
Bridge Loading Output	31
Debug Output	32
Other Considerations	32
SENSITIVITY TESTING OF LOAD GENERATOR	33
Potential Input Parameter CAndidates	33
Analysis of the Candidate Parameters	36
Parameters to be Tested	42
Parameter Test Order	43
Sensitivity Test Specification	44
Conduct and Results of Tests	48
BRPOS Testing	49
SIMTIM Testing	60
DELTIM Testing	72
Restricted Zone Testing	93
Unidirectional	94
Bidirectional	95
SDFAC Testing	106
DEVELOPMENT OF THE DYNAMIC STRESS PROGRAM	114
Structural Analysis	115
Simple Support Span and Continuous Span	119
DESCRIPTION OF ANALYTIC METHODOLOGY DEVELOPED	139
Stress Histogram Program	152
Truck Trace Construction	153
Point Trace Algorithm	154
Platoon Construction	155
Stress Range Determination	163
Application of the Approach	167

TABLE OF CONTENTS (CONTINUED)

	Page
GENERATED HISTOGRAMS AND RESULTS	172
U.S. 301 and Md. Rt. 5	175
U. S. 301 and Western Branch	197
I-495 and U. S. 1	206
I-83 and Bunker Hill Rd.	224
Dumbries Bridge	241
Overall Results	262
CONCLUSIONS AND RECOMMENDATIONS	264
General Comments	265
The BRIGLD1 Simulator	266
The Dynamic Structural Analysis Program	269
The Stress Signature Program System	271
Other Considerations	274
Summary	274
REFERENCES	276
BIBLIOGRAPHY	277

LIST OF FIGURES

Figure	Title	Page
1	Traffic Simulation BAsed System	2
2	Axle Signature Based System	4
3	Vehicle Buffer Allocation Initial	25
4	Vehicle Buffer Allocation Vehicles Added	26
5	Vehicle Buffers Modified	27
6	BRIGLD1 Output for U.S. 301 and Rt. 5	178
7	BRGSTRS Output for U. S. 301 and Rt. 5	187
8	BRIGLD1 Output for U.S. 301 and Western Branch	199
9	BRIGLD1 Output for I-495 and U.S. 1	210
10	BRGSTRS Output for I-495 and U.S. 1	218
11	BRIGLD1 Output for I-83 and Bunker Hill Rd.	226
12	BRGSTRS Output for I-83 and Bunker Hill Rd.	233
13	BRIGLD1 Output for I-95 Dumfries, Va.	245
14	BRGSTRS Output for I- 95 Dumfries, Va.	255

LIST OF TABLES

Table No.	Title	Page
1	200 ft. Roadway Approach Test	51
2	1000 ft. Roadway Approach Test	52
3	4000 ft. Roadway Approach Test	53
4	10,560 ft. Roadway Approach Test	54
5	26,400 ft. Roadway Approach Test	55
6	Variation from Given Traffic Population Distribution	56
7	Variation from Given Platoon Distribution	57
8	One Hour Simulation Time Test	61
9	Two and One Half Hour Simulation Time Test	62
10	Four Hour Simulation Time Test	63
11	Five Hour Simulation Time Test	64
12	Ten Hour Simulation Time Test	65
13	Variation Comparison	68
14	Generated DELTIM Test Data	75
15	Comparison of Behavior for 1.5 sec. vs .5 sec. DELTIM	77
16	Comparison of Behavior for 2.0 sec. vs .5 sec. DELTIM	84
17	Comparison of Behavior for 1.0 sec. vs .5 sec. DELTIM	87
18	Comparison of Case Variations from .5 sec.	92
19	Auto Safe Distance Value (60mph) vs SDFAC	111
20	Platoon Distribution of Bridge Captured Loads	113
21	Comparison of Measured, Simulated and Directly Calculated Stress Maxima (I-83 and Bunker Hill Rd.)	171
22	Comparison of Truck Distributions for the U.S. 301 and Md. Rt. 5 Bridge	176
23	Comparison of Measured and Predicted Incidence of Bridge Stress Maxima (U.S. 301 and Md. Rt. 5)	186
24	Comparison of Truck Distributions for the U.S. 301 and Western Branch Bridge	198
25	Comparison of Measured and Predicted Incidence of Bridge Stress Maxima (U.S. 301 and Western Branch)	207
26	Comparison of Truck Distributions for the I-495 and U.S. 1 Bridge	208
27	Comparison of Measured and Predicted Incidence of Bridge Stress Maxima (I-495 and U.S. 1)	216

Table No.	Title	Page
28	Comparison of Truck Distribution for the I-83 and Bunker Hill Rd. Bridge	225
29	Comparison of Measured and Predicted Stress Maxima (I-83 and Bunker Hill Rd.)	240
30	Comparison of Truck Distributions for the Dumfries Bridge	242
31	Comparison of Measured and Predicted Truck Weights (I-95 Dumfries, Va.)	244
32	Comparison of Measured and Predicted Incidence of Bridge Stress Maxima (I-95 Dumfries, Va.)	252
33	Comparison of Measured and Predicted Incidence of Bridge Stress Maxima on Beams 2 and 3 (I-95 Dumfries, Va.)	253

LIST OF ABBREVIATIONS AND SYMBOLS

A	The Area of the Moment Diagram
B_L	Bridge Length
C	The distance to the neutral axis
Ec	The Modulus of Elasticity for Concrete
Es	The Modulus of Elasticity for Steel
$[F(t)]$	The force vector at time t created by the live traffic load
I	The moment of inertia
$[K]$	The unit load stiffness matrix
l	The length of the span
m	The mass of an element (grid) of the bridge
M_D	The discontinuity moments
M_{pi}	The discontinuity due to the load p at location i
NL	Lane Number
t	Time in seconds
t_1	Thickness of the bridge deck
V	Vehicle speed
W	Weight
X	The longitudinal distance
Z_{C1}	The sectional modulus for the upper fiber
Z_{C2}	The sectional modulus for the lower fiber
$[\delta]$	The displacement vector

$\ddot{\delta}$	The acceleration of the element
Δt	Increment of time
ν_C	Poisson's ratio for concrete
ν_S	Poisson's ratio for steel
$\sigma(t)$	The dynamic stress
σ_B	The bending stress
τ	The lag time between a pair of axle loads

INTRODUCTION

The work performed and the results obtained under Contract FH-11-7904 to the Federal Highway Administration, Structures and Applied Mechanics Division, for a study on "Prediction of Loadings on Highway Bridges--Phase II", is described in four separate reports, FHWA-RD-73-42, 43, 44 and 45.

A primary objective of this study was to extend the traffic simulator computer program developed by the Kelly Scientific Corporation to a useable engineering tool capable of generating bridge loads. It was further the purpose of the study to develop a finite element stress analysis program, including dynamic effects due to the live load, which directly interfaced with the load generator, produce several stress histograms for various bridge and traffic configurations, and to develop and implement an alternative method based upon analytic methods rather than traffic simulation.

Report FHWA-RD-73-42 describes the work performed in the study. This includes the background which led to the work performed, a description of the work performed and problems encountered in revising BRIGLD1. The results of sensitivity testing of BRIGLD1, development of the stress program, generated histograms, description of the analytic methods investigation, and the conclusions and recommendations are also included.

Report FHWA-RD-73-43 is the Users Manual which provides utilization instructions, data preparation instructions, output and variables definitions and a description of the BRIGLD1 computer program. The description includes a narrative description section, flow charts and program listings on the main line program and each subroutine. The use of this program for stress range prediction is illustrated in Figure 1.

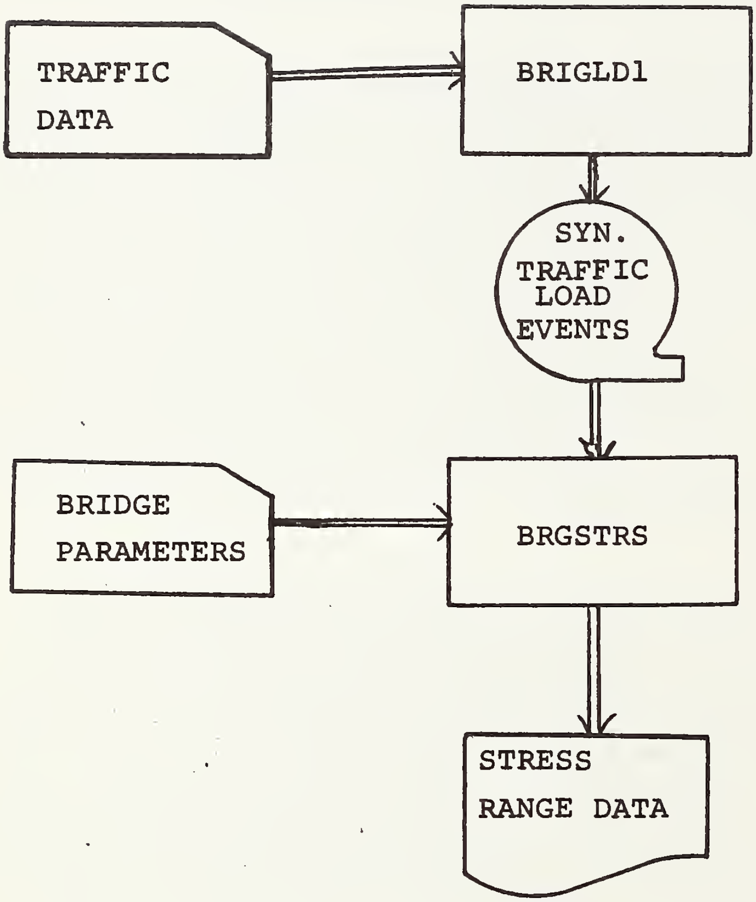


Figure 1. Traffic Simulation Based System

Report FHWA-RD-73-44 is the Users Manual for the dynamic stress analysis computer program, BRGSTRS. This report contains the same descriptive type matter as indicated above for BRIGLD1.

Report FHWA-RD-73-45 contains the Users Manuals for two computer programs which operate as a system with BRGSTRS. The first is the Synthetic Load Generator, SYNGEN, which generates single axle loads for the dynamic stress analysis program, which in turn generates a stress signature curve, trace, for each defined axle load. The second is the histogram computer program, HISGEN, which generates long-term stress range histograms from the synthetic single axle stress trace data generated by the dynamic stress analysis program, as shown in Figure 2. This is accomplished by first forming composite truck stress traces for a given truck population from the single axle data. Then, forming composite truck platoon stress traces for a given platoon population. Long-term effects are estimated from traffic density estimates and the estimated incidence of each platoon configuration. The information contained in this report, for both SYNGEN and HISGEN, is of the same form as described above for BRIGLD1.

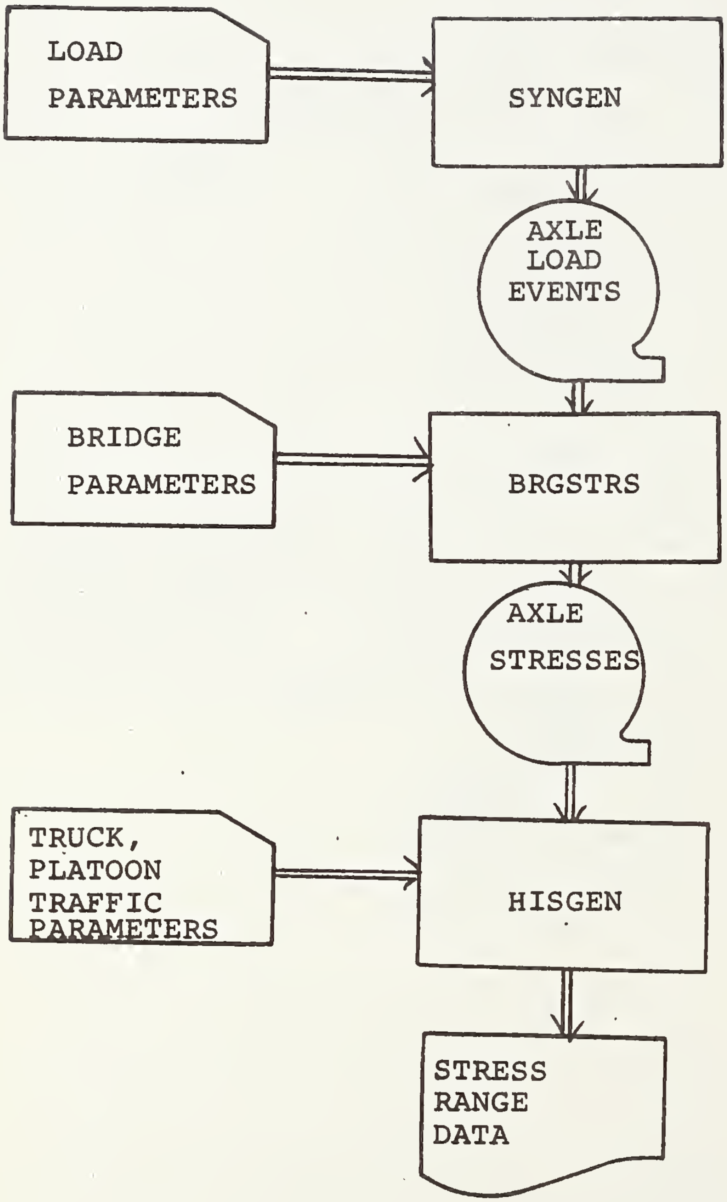


Figure 2. Axle Signature Based System

BACKGROUND

Reference (1) describes the work performed under contract FH-11-7314 in developing a traffic simulator computer program (BRIGLD1) for the purpose of Forecasting of Heavy Loading Patterns on Highway Bridges. The purpose of this work was toward developing better techniques for predicting long-term fatigue of bridges, specifically the main beams. This work was completed in June 1970.

The initial form of this program was developed on a CDC6600 in Run FORTRAN. Subsequent to delivery of the program to the Federal Highway Administration, the program was modified to be compatible to IBM (360/65) FORTRAN IV.

In February of 1971, the Federal Highway Administration solicited research and development study proposals for Phase II of the work. The problem, which the research and development study was to attack, was defined as follows:

> "The bridge loading simulation model in its original state was able to forecast certain combinations of loadings on bridges. Parameters accounted for in the model were total traffic, percent of truck traffic, separation of trucks by types, separation of types into several axle groupings and weight distributions, geometric highway features, vehicle speed, passing maneuvers, traffic direction, and number of lanes. Of interest was the summation of certain critical loading combinations on various lengths of bridges.
>
> "The model was not thoroughly tested and stopped short of converting loading combinations into stresses. The model, in its original configuration, was only an intermediate research tool which was not directly useable by bridge engineers.

"Accompanying the development of the model was a limited amount of analytical development of bridge loading forecasting. The analytical work was intended to supplement results from the model.

In June 1972, this firm was awarded the Phase II study by the Federal Highway Administration.

The objectives of the study were to:

1. Perform a sensitivity analysis on the simulation model (BRIGLD1) to evaluate the effects of changes in all the important parameters.
2. Extend the scope of the model to include the calculation of stress in representative bridge members.
3. Prepare charts or tables of stress histograms based on several bridge and traffic configurations which are suitable for use as design guides.
4. Extend the analytical approach to load estimation, and use the resulting analysis for comparison and verification of the simulation results.

In order to satisfy these objectives, the work was defined in terms of four major tasks, i.e.,

1. Sensitivity Analysis
2. Extend Model to Stress Calculations
3. Prepare Stress Histograms/Tables
4. Extend the analytical Approach

The specifications of the work required under each of these tasks are presented in the following subsections.

Task I - Sensitivity Analysis

Vary all the input data over the allowed range of each element of data, from extrema to extrema, and all Input/Output control data and option elements for the purpose of testing and validating BRIGLD1.

Establish guidelines for user selection of parameters and verify the remaining part of the functional performance of the simulator and accomplish accuracy testing at the same time. This would be accomplished through the use of a selected set of test cases. Each case would be run with a particular parameter varying over its allowable interval; wherever possible, multiple parameters would be varied during a given run, as long as their effect was independent. Checks of the results of each calculation were to be performed to verify the accuracy of the corresponding programmed calculation.

Where inaccuracies were detected, reasons would be investigated and solutions sought and incorporated into BRIGLD1 in consultation with the contract manager.

Once valid functioning and accuracy of the simulator was achieved, a parametric variation on the significant parameters utilized by the simulator would be performed. The choice of parameter variations would be guided by an analysis of the equations and of the dependent and independent relationships of the simulator in order to accomplish the desired results with a minimum number of computer runs.

Task II - Extend Model to Stress Calculations

The original simulator program provided time-dependent traffic loadings for bridges. It accumulated the vehicle weights that pass off the roadway and onto the bridge within specified time intervals. The contractor was to transform this data into a suitable form for distribution to the bridge deck. At each

time increment (determined by the user) the spatial distribution and associated magnitudes would be sampled and the live-load calculated and appropriately distributed. From the distributed loads the corresponding bridge stresses would be calculated at critical points to be specified by the user.

In calculating the stresses, dynamic effects were also to be considered. The added dynamic load would be superimposed on the bridge span. The approach utilized would be similar to that used in the computer program from the Illinois highway research program. The actual vehicle axle loadings would be distributed to the lateral and longitudinal beams, and then to the girders via a 2-dimensional mesh. Also to be included would be a user option that would allow the retention of the load data, as a function of time and location, on magnetic tape for future use. Continuous as well as simple spans would be considered, along with reinforced or prestressed concrete or steel beam bridges. The stress routine would be modular in that other types of bridges, such as box beam or orthotropic plate, might be added by the user if so desired. The materials would be assumed to be fatiguing metals.

The stress calculation portions would directly interface with the load simulator at each increment of time during the simulation.

The finite element method would be utilized to perform the stress calculation. The assembly of the stiffness matrix of the bridge member with the nodal forcing function would enable the calculation of nodal displacements.

Subsequently, the strain matrix was to be obtained and finally the stresses would be computed. The various existing programs or subprograms would be considered and adapted with some modification for tailoring to the bridge structural members.

The simulation program would be verified through reasonable agreement between comparisons of the strain or stress output of the simulator with values obtained from available observed data (data was to be obtained through consultation with FHWA).

From the developed simulator, the pattern of loadings on the bridge member due to a loading would be utilized in the stress histogram would be determined in this portion of the work and output in tabular and graphical hard-copy forms. The precise format of these outputs would be submitted to the FHWA for review and approval prior to the performance of Task III.

Task III - Prepare Stress Histograms/Tables

The stress portion of the program would output the stress history data as stress-histograms in both tabular and graphical forms. A user option was also to be included to allow output of the ordered time-dependent stress history generated by the simulator.

The actual number and types of configurations would be submitted to the FHWA for review and approval. The approval cycle was to be the normal 30 days from time of submission. The stress histograms for approximately ten bridges and traffic configurations would be prepared. It was envisioned that this would consist of six different bridge configurations of which four should have two sets of traffic configurations. The configurations would allow for a comparison of types, lengths, widths, and loads.

Upon acceptance by the FHWA of the prescribed bridge and traffic configurations to be used as the basis for developing the tabular and graphical stress histograms, the contractor would generate the necessary input data, verify and validate it, and operate the load simulator-stress calculation system on the data. The output from this would be submitted in draft form to the FHWA for review and approval for inclusion in the final

report. This would be done substantially before the submission of the draft version of the final report in order to allow adequate time for any reruns.

Task IV - Extend the Analytical Approach

The extension of the loading prediction capability through "analytical methodology" would be accomplished through the development of a probabilistic-based load prediction technique. This technique would be implemented as a computer program to provide load histograms for test cases. These test case load histograms would be compared to the load histograms produced by the BRIGLD1 Simulator for the same test cases.

The probabilistic techniques would utilize such significant traffic behavioral characteristics as flow rates, propagation/density, flow patterns, lane changing, vehicle types, platoon lengths, platoon composition, platoon size, load propagation, and load distribution.

Deficiencies in the BRIGLD1 Simulator

As work progressed in familiarization and investigation of the original BRIGLD1 simulator, it became evident that the program was almost totally unsuited for the objectives of the study. Further, coding errors and poor representations were discovered in the simulation model. These factors caused the planned attack, to satisfy the study objectives, to be completely revised. The primary and priority effort became one of salvaging the traffic simulator for use as a bridge load generator. All other efforts were relegated to subordinate positions until this problem was solved adequately. Hence, the sensitivity analysis actually became a subtask in the major task of salvaging the simulator.

Parallel efforts were carried on for the stress analysis program and the analytic method effort. However, the impact of the original simulator forced performance of the histogram

generation task to the very end of the project, due to the shifting of the completion of the stress analysis program.

DESCRIPTION OF WORK ON BRIGLD1 SIMULATOR

Nearly a 100% rework of the BRIGLD1 simulator was required. Only 30% of the original program was retained in the final version produced in this effort. However, that 30% required significant modification and correction.

Some general observations on the BRIGLD1 simulator to be used for the generation of bridge deck loads are presented herein, and the work performed. Specific comments on programming problems are also discussed in this section. In general, the simulator was not designed for the purposes of structural analysis of bridges. The originally generated statistics and output data did not satisfy the needs of deck load data for use in structural analysis. Mostly, the original output data reflected the traffic generating capability of the simulator. It was recommended that all of the statistical programs be eliminated and simple, user controlled, statistical output be provided that would allow a user to verify the proper generation of truck traffic for his defined bridge. This significantly reduced the program size and had some effect on running time, in that substantial data handling was eliminated.

The manner in which the data representing the motion and positions of the vehicles being simulated was being handled in the original program was extremely inefficient. State-of-the-art methods in the use of pointers and buffers had not been utilized. It was this particular problem which caused the excessive use of computer time, e.g., only a 2 to 1 compression ratio of real time to computer time.

The arbitrary class interval size on truck loads was not realistic in terms of bridge response properties and required change.

Another significant cause of excessive computer utilization was the motion simulation and handling of non-truck traffic. Approximately 5/6 of all of the vehicles generated in the traffic data contained in the program, was non-truck traffic. In this case, for a U.S. 301 bridge in Md., the motion of these vehicles was simulated over 7000 feet of roadway, per lane. On the basis of the data available for this particular bridge, truck traffic occurred on an average of one per two minutes. (It should be noted that the simulator erroneously generated at three per minute in the originally reported results.) At the rate of one per two minutes, and a rough assumption of two cars per truck, only 1-1/2 vehicles per minute need be simulated. Further, only those non-truck vehicles which would occupy a portion of the bridge deck, at some time during the passage of a truck over the deck, need be simulated. Hence, for the given test data only approximately 50 vehicles need be generated over a simulated 33 minutes. Be reducing the simulator to an event type simulator, rather than a continuous time simulator, where the event would be the generation of a truck(s), approximately 50% of the computing time could be saved, i.e., based upon using a 7000 foot roadway. As the roadway becomes longer, the savings in computing time increases.

As a result of this evaluation it was recommended and agreed upon that the program be modified to use an event type approach, each event being the generation of a truck, or platoon. This was to be accomplished by forming an envelope about each truck, or platoon, which would essentially contain all of the non-truck vehicles which would be on the bridge deck with the truck or platoon, as an example:

> Simple logic could be used if a user inputs maximum and minimum truck and non-truck traffic speeds. The

program need only generate autos for approximately 3500 feet of roadway. Any non-truck traffic exceeding this distance down the roadway prior to a truck event may be discarded. Any non-truck traffic generated after approximately 3500 feet behind a truck event would depend on the subsequent occurrence of a truck event. An approach of this nature would provide substantial savings in computer time.

While the above modification was initially planned for implementation subsequent developments indicated that it was unnecessary in the program as it was being revised. This was primarily due to the improved vehicle data handling methodology and determination that a shorter roadway provided more realistic behavior than the longer 7000 foot roadway.

It should be noted that the only traffic data available in and established for the program was for a Md. bridge on U.S. 301. This data was not necessarily valid for use on any other bridge and theoretically applies only to the one bridge.

An option existed in the original program, the parametric bridge length option, that served no current need. It provided variations of deck sampling lengths for the specific parametric and distribution data defining a given section of highway. Since the traffic data collected for a given bridge is essentially unique to that bridge, it can be established that it is not, in general, suitable to any other bridge. Also since the structural configuration of a bridge is essentially unique, the incremental lengthening of a specific bridge has no meaning. Hence, it was recommended that this option be eliminated. Subsequently the design of the revised program and the interface philosophy to the structural program obviated this option anyway.

It was further determined that with multiple bridge lengths the first bridge must be the longest when specified in this option. Otherwise, subsequent ends of bridges would be identical to the first bridge. This was not specified in the user information of the original program documentation.

The original program did not directly generate truck platoons, nor did it attempt to preserve the actual platoon statistics for a given bridge. Any platooning that may have occurred was incidental to the simulation. A more realistic basis for the generation of a truck platoon should be established in the original program by the introduction of realistic grades of the bridge approaches and realistic truck traffic behavior on the grades. Also, a higher correlation of weight and speed relationships should be established. However, this would amount to a substantial effort with questionable results.

A more realistic approach was to superimpose a truck platoon routine over the original vehicle generator which preserves platoon statistics. This was recommended and implemented.

It should be noted that for the purposes of this program a truck platoon is defined as a load event where a truck axle is on the bridge or will go on the bridge during an integration interval. The event lasts until there are no truck axles on the bridge.

The original simulator had a fairly complex passing logic contained in it for bidirectional and unidirectional two-lane highways. It was recommended that it be evaluated in terms of its significance to the objectives of bridge load prediction and structural analysis. Relative to this problem the whole concept of roadway/traffic simulation for the purposes of bridge structural analysis becomes

questionable, in terms of its analytic contribution. It was the opinion of the investigators that a straight forward truck traffic generator, which preserves observed statistics on a bridge deck, would have been far more meaningful and certainly more economical than the BRIGLD1 simulator.

There were, besides programming deficiencies and those indicated in the above discussion, certain utilization deficiencies in the simulator. Some of these are defined below:

1. To satisfy the needs of modern highway designs and the ever present increasing highway widths, it was recommended that the program be modified to handle multiple unidirectional bridges of up to six lanes. However, as work continued and the questionable value of the use of the BRIGLD1 simulator increased, it was decided that no immediate effort be expended to provide this capability.

2. It was also recommended that the maintenance of the bidirectional two-lane highway simulation whould be evaluated as to its value to the Federal Highway Administration. If it would be of little value, it whould be eliminated. This would significantly reduce the size of the simulator and the complexity of its logic.

3. There was no minimum vehicle speed provided in the original simulator. This was unrealistic and could be a source of unnecessary computer utilization, and logic problems. A minimum vehicle speed, as a user input and a control on the vehicle motion, was recommended and implemented.

4. The traffic generated did seem to preserve the distribution statistics which were used as input to the program

for short runs. There was, however, some evidence of degradation of the randomness of the "random" numbers generated for longer runs. This appeared to be due to one single seed used to generate all random data. If serious use is to be made of the BRIGLD1 simulator, especially for long runs, the program should be modified to use separate random number seeds to generate distinct functions, i.e., one each for vehicle type, speed, weight, platoon size, etc. Also, for long runs each of these functions should be reseeded periodically.

5. Additional consideration should be given to making vehicle performance relate better to the vehicle's weight and power. Consideration is given to this relationship only in the calculation of acceleration in the present form of BRIGLD1.

6. Further, a significant number of programming errors were initially uncovered in the preliminary work and more uncovered during debug testing and sensitivity testing. Some of the originally discovered errors are shown below:

PROGRAM ERRORS

Program	Line	Error
INDATA	528	Read restricted zone data from unit 6 - must be 5, 6 is the line printer. Note: that REZONE has never been used or tested.

PROGRAM ERRORS (Continued)

Program	Line	Error
PASPOS	571/575	Repeat of same statement, SPDIFF=ABS (SPD (MU,1)-(ILV,1))
PASPOS	589	Equation of the form: $(D^2/AM-.5D^2/AM)-C$, excessive coding here
SORPOS	1043	IF(LANE(18)) 3,3,2 should be: IF(LANE(IB)) 3,3,2
SORPOS	1044	2 IBB=TB should be 2 IBB=IB(TB does not exist)
SORPOS	1078	22 IBB=TBB+3 should be: 22 IBB=IBB+3, (TBB does not exist)
SUMCK	1228	EQUIVALENCE (DIFF(51), HOUR) 50 values of HOUR are overwritten by DIFF values 51 to 100 in SUMLD. However, HOUR is accumulated from call to call and must be saved.
BRGLD	20/48	Plot tape number read in under label NPLOT and used in program as IPLOT
CONTRO	206	NR not initialized in the program before it is used.

Specific recommendations that were made with regard to improving the coding of the simulator included:

1. Subroutines used in the program GEN, vehicle generation, HDWAY, TYPE, SPEED, WEIGHT functions were extremely trivial

and should have been done in line. In addition, the HDWAY, SPEED AND WEIGHT funcitons included a linear interpolation which was being solved by use of an iterative process when it should have been a simple explicit solution.

2. The DTNRD subroutine used by READ should have been done in line.

3. All moving of vehicle data - RENUM, PASTES, SORPOS, should be eliminated and replaced by pointers for each vehicle to vehicle ahead and vehicle behind, and a buffer allocation scheme to assign vehicle data location in the tables. All searching for vehicle ahead and behind should be eliminated and pointers used to simplify logic in UPDATE routines.

4. The POS(IV,1) array should be reduced to a singly indexed variable POS(IV).

The details of the work performed on BRIGLD1 is described in the following subsections:

User Data Input
Traffic Generation
Vehicle Data Buffer Handling
Statistical Output
Bridge Loading Output
Debug Output
Other Considerations

The program description, including listings and flowcharts, appear in FHWA-RD-73-43, Users Manual for BRIGLD1.

The list of variables was corrected, updated and expanded to reference all subroutines using the variable, and to include units of measurement where applicable.

User Data Input

The entire data input portion of the BRIGLD1 Simulator was rewritten with the user in mind. The data input required by the original program placed an extraordinary burden on the engineer using the program. Also, in some cases, formats were specified such that significant data was lost and zeros were read. All single data variables were placed in a namelist and given default values within the program.

Default values were assigned on the basis of normal design use of the program and on the basis of results from the sensitivity testing. These variables, their default values, units, and recommended use are described in the Users Manual. Most of the tabular data input was also redesigned and data input forms generated for this data. Default values were assigned again to all tabular data. Default values for these variables is currently set to the values used in the original simulator and the traffic distribution is that of U.S. 301 in Md. Truck types are basically the same as that used by the original simulator except for corrections required for some lengths and weight distributions. All double axles were compressed to single axle values at the midpoints. Default values of the tabular data were coded in the Block Data Program and can be easily changed. A platoon distribution table was added to allow the user to generate platoons according to a specific distribution. The BRIGLD1 simulator did not, specifically generate or maintain truck platoon statistics. It relied totally upon the adequacy of its traffic simulation.

A printout of all data input and default values used have also been added to the program.

Traffic Generation

The traffic generation is functionally the same as the original However, many small subroutines were eliminated and coded "in line" in the GEN subroutine. Also, several program interpolation loops were replaced by a simple solution of an interpolation equation saving many lines of code, and computer time. The vehicle type generation was expanded to include the truck platoon generation, previously mentioned. If a platoon distribution is not input, all trucks are generated as a single truck event and platooning will take place as it did in the original version.

A deficiency in the time of vehicle generation was corrected. The original version generated a time, HDWY, for the next vehicle to be generated. This time was decremented by the integration interval Δt until it reached zero or a negative number. The vehicle was then generated at position 0 and a new HDWY generated. This method adds an average of 1/2 Δt to each HDWY time decreasing the amount of traffic generated. This was corrected by adding the new HDWY to the residual (0, or negative less than Δt) and by placing the vehicle generated on the roadway at the distance it would have travelled, i.e., SPD X (-residual time).

Currently traffic is generated only in the right lane. Consideration should be given to generating traffic in both lanes according to an input distribution. If the simulator is expanded to more than two lanes or if an extremely short roadway is used this expansion of the program would be necessary.

Vehicle Data Buffer Handling

The BRIGLD1 simulator used excessive computer time in the continuous shifting of all data related to a vehicle whenever its relative position changed. Also, excessive time was being used in searching for vehicles ahead and behind. All of the searching and data shifting was eliminated and replaced by a buffer allocation scheme which kept track of vehicles ahead, behind, and the location of the related data. Three tables were added, IFWD, IBAK, and INDX. These tables must be the same length as the data buffers, ITYPE, WGT, POS, LANE, etc. The length of these buffers was shortened from 1200 to 400 words and could have been easily shortened to 100 for the recommended approach roadway of 1000 ft. Some minor program modification would be required to change the buffer length. The program was also modified, such that in the event buffer space was not available, a vehicle was generated as soon as space was available without disturbing the traffic statistics. A detailed description of the vehicle data buffer allocation methodology is presented below.

Three buffer allocation tables were generated - IFWD, IBAK, and INDX. The INDX table contains the pointer to the vehicle data, that is, SPD, ACC, POS, WGT, KSTAT, ITYPE, and LANE. ACC (acceleration data buffer) has been added to the original program. Initially, the INDX table was ordered sequentially starting with the second element in the table referencing the first vehicle data elements. The first position of this table is not used.

All vehicles are positionally ordered through use of the IFWD and IBAK pointers. The first IFWD element points to the INDX table position referencing the forward most vehicle on the road. The IFWD element referenced by the first IFWD element points to the INDX table position referencing the vehicle directly behind the most forward vehicle on the road, etc.

The IBAK table strings the vehicles together in the other direction, that is, from last to first. The first element of the IBAK table points to the INDX table position referencing the last behicle generated or last on the road. The IBAK element referenced by the first IBAK element points to the INDX table position of the second last car on the road, and so forth.

The tables are initialized as follows:

IFWD(I) = I + 1, I = 1, 399

IFWD(1200) = -1

IBAK(I) = I - 1, I = 2, 400

IBAK(1) = 1

INDX(I) = i - 1, i = 1, 400

When a vehicle is generated, its data is assigned to the position referenced by the INDX value at the forward (IFWD) reference of the last vehicle generated, i.e., at INDX(IFWD(IBAK(1)). The last vehicle generated reference is changed:

BAK(1) = IFWD(IBAK(1))

When a vehicle at POS(INDX(J)) is passed by its IFWD referenced vehicle, POS(INDX(IFWD(J)), the pointers in the INDX table at position J and at IFWD(J) are interchanged.

Any number of vehicles in a string from J to K may be eliminated by inserting the string at the position of the next vehicle to be generated and connecting the J-1 and K-1 vehicles by changing the following forward and backward references:

IFWD(K) $\longrightarrow$ TEMP
IFWD(IBAK(1) $\longrightarrow$ IFWD(K)
J $\longrightarrow$ IFWD(IBAK(1))
TEMP $\longrightarrow$ IFWD(IBAK(J))
IBAK(TEMP) $\longrightarrow$ IBAK(IFWD(K))
IBAK(J) $\longrightarrow$ IBAK(TEMP)
IBAK(1) $\longrightarrow$ IBAK(J)

J may be equal to K (one vehicle only) and the string may appear anywhere including the forward or backward ends of the traffic.

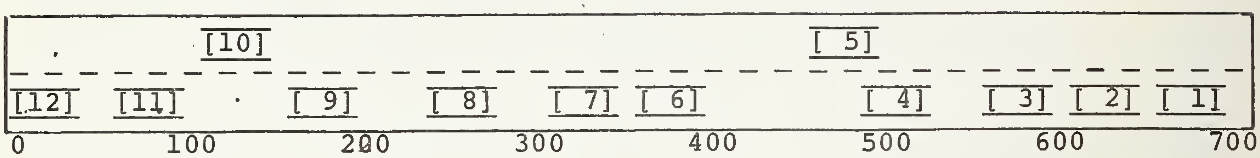
The following examples are offered to illustrate the use of the IFWD, IBAK, and INDX tables (limited here to a length of 16). The positional and lane vehicle data tables are included in the examples, see Figures 3 through 6.

Initialized tables:

I	IFWD	IBAK	INDX	POS	LANE
1	2	1	0	-	-
2	3	1	1	-	-
3	4	2	2	-	-
4	5	3	3	-	-
5	6	4	4	-	-
6	7	5	5	-	-
7	8	6	6	-	-
8	9	7	7	-	-
9	10	8	8	-	-
10	11	9	9	-	-
11	12	10	10	-	-
12	13	11	11	-	-
13	14	12	12	-	-
14	15	13	13	-	-
15	16	14	14	-	-
16	-1	15	15	-	-

Figure 3. Vehicle Buffer Allocation Initial

Now we will generate 12 vehicles on the road:

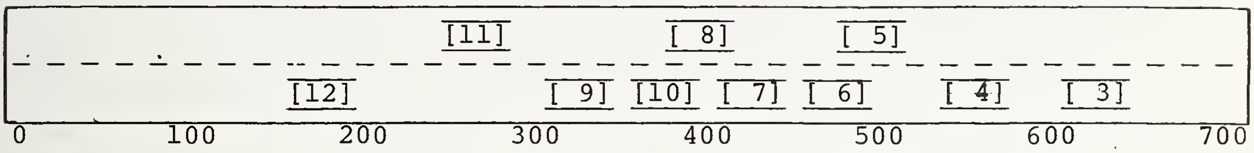


Updated Tables:

I	IFWD	IBAK	INDX	POS	LANE
1	2	13	0	700	1
2	3	1	1	650	1
3	4	2	2	600	1
4	5	3	3	525	1
5	6	4	4	500	2
6	7	5	5	400	1
7	8	6	6	350	1
8	9	7	7	275	1
9	10	8	8	200	1
10	11	9	9	150	2
11	12	10	10	100	1
12	13	11	11	25	1
13	14	12	12	-	-
14	15	13	13	-	-
15	16	14	14	-	-
16	-1	15	15	-	-

Figure 4. Vehicle Buffer Allocation Vehicles Added

Next vehicle No. 10 will pass vehicle No. 9 and vehicles 1 and 2 will be deleted as they leave the roadway:

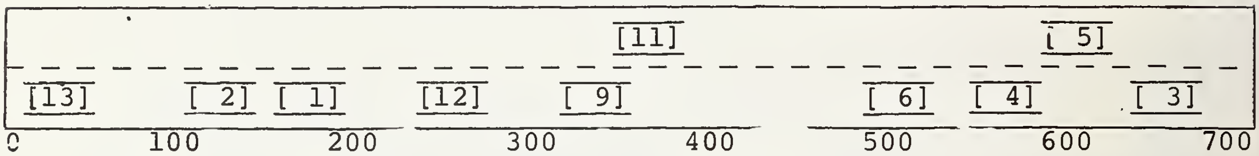


Updated Tables:

I	IFWD	IBAK	INDX	POS	LANE
1	4	13	0	-	-
2	3	13	1	-	-
3	14	2	2	650	1
4	5	1	3	575	1
5	6	4	4	525	2
6	7	5	5	500	1
7	8	6	6	450	1
8	9	7	7	425	2
9	10	8	8	350	1
10	11	9	10	400	1
11	12	10	9	275	2
12	13	11	11	200	1
13	2	12	12	-	-
14	15	3	13	-	-
15	16	14	14	-	-
16	-1	15	15	-	-

Figure 5. Vehicle Buffers Modified

Three more vehicles are generated, (1, 2, and 13), vehicle 5 will pass vehicle 4, and vehicle 11 will pass vehicle 9. Then vehicles 10, 8, and 7 are eliminated as non truck influencing:*



Updated tables:

I	IFWD	IBAK	INDX	POS	LANE
1	4	14	0	175	1
2	3	13	1	125	1
3	14	2	2	700	1
4	5	1	3	600	1
5	6	4	5	650	2
6	7	5	4	550	1
7	11	6	6	-	-
8	9	14	7	-	-
9	10	8	8	350	1
10	15	9	10	-	-
11	12	7	11	375	2
12	13	11	9	250	1
13	2	12	12	50	1
14	8	3	11	-	-
15	16	10	14	-	-
16	-1	15	15	-	-

Figure 5. Vehicle Buffers Modified (Cont.)

*The elimination of car traffic determined not to be in the range of influence of truck traffic has not been implemented in view

Bidirectional traffic is handled by splitting the 400 word buffer allocation tables into two, 200 word tables:

One Direction	Bidirectional Traffic	
Forward	Forward	Reverse
IFWD(400)	IFWD(200)	JFWD(200)
IBAK(400)	IBAK(200)	JBAK(200)
INDX(400)	INDX(200)	JNDX(200)

The first half of the data buffers (1-200) are then allocated to the forward direction traffic and the second half (201-400) are allocated to the reverse direction traffic. Reverse traffic direction tables operate then in the same manner as the forward traffic direction tables.

Vehicle Motion

Vehicle motion is essentially the same as is described in (1) as far as passing and acceleration decision logic is concerned. However, major changes were made to this portion of the program. The original version started with the foremost vehicle, deciding its passing status, acceleration, and changing its position immediately. Status and acceleration decisions for all following vehicles were made on the basis of all vehicles forward of it integrated to the next time step, while all vehicles behind were in the present time step. This was changed in the "Bridge Load Generator" to a two step process, decision and integration, where, starting with the foremost vehicle, status and acceleration decisions were made for all vehicles at positions in the same time step. Lane changes are, however, still made during the decision phase. All vehicles are then integrated forward on the basis of acceleration and the old speed. This required the addition of an acceleration table, ACC. Speed is then changed only by acceleration.

---

of the current compression of computer running time relative to simulation time and the recommendation of a short roadway (approximately 1000 ft), as indicated earlier. The example does illustrate how to eliminate one or more vehicles from the middle of the roadway.

Significant coding errors, in addition to those described earlier, were found in the vehicle motion portion of the program and were eliminated. A debug routine, GRAPH, was generated in order to visualize the motion of vehicles on the roadway. This printout is obtained along with allocation buffers and position, acceleration, status and speed data for each vehicle by setting the DBUG parameter "True" during program data input. There was no way to "see" or verify traffic motion and behavior in the original simulator.

There are still some problems with bidirectional traffic with occasional "crashes" of passing cars not completing the pass in time where extremely dense traffic is encountered, as in the originally defined traffic data. In general, however, the bidirectional traffic behaves reasonably well, but was of questionable value to the objectives of this effort.

Statistical Output

The statistical output and statistic gathering portions of the original simulator were entirely replaced.

The following statistics and data are gathered by the revised "Bridge Load Generator (BRIGLD1)":

1. Total vehicles generated.

2. Simulated time - starting from the time the first vehicle enters the bridge.

3. Platoon distribution of 1 through 9 and 10 and above. This statistic is gathered on the bridge and at the time the platoon is generated, both forward and reverse directions. A truck is part of a platoon on the bridge if it enters the bridge during a time frame when there is

still all or part of another truck on the bridge or during the next following time step.

4. Type distribution - this statistic is gathered as the vehicle enters the bridge.

5. Load distribution - this statistic is gathered as the vehicle enters the bridge and is distributed according to class intervals specified by the user.

6. Statistical output is provided at the conclusion of a run, and at every simulated hour of the run.

Bridge Loading Output

The Bridge Loading Output portions of the program are additions to the original Simulator. Bridge loading data is output whenever there is either a truck on the bridge or one is entering the bridge during the next time frame. This data is associated with a loading event number. Three types of data are output:

1. General
   Simulation time
   Load event number
   Integration time increment
2. Load Data - by axle
   Number of axles on/going on the bridge
   Position relative to the start of the bridge
   Lane
   Axle weight - may be a double axle
   Distance the axle will travel during this integration step
   Acceleration
3. Vehicle identification

Number of trucks on/going on the bridge since start
of this event

Truck Type

Truck Weight

Truck Speed

Lane

Time of truck entering the bridge

The position of a vehicle axle is referenced to zero at the beginning of the pseudo bridge.

Debug Output

A printout of the following data is available by setting the DBUG parameter to TRUE during program data input.

Vehicle generation data

Printout of buffer allocation tables and
vehicle data buffers

Printout of the roadway and bridge up to 6000 ft
and two lanes with vehicle numbers showing
positionally on the roadway

Printout of bridge loading data

An example of the debug output is provided in Appendix A.

Other Considerations

The use of multiple bridge lengths was eliminated as being unnecessary. However, bridge loading data should be generated for the longest anticipated bridge and is directly useable for any shorter length bridge.

SENSITIVITY TESTING OF LOAD GENERATOR

The first task required by the contract was to perform sensitivity testing of the input parameters of the Government furnished bridge loading program. As was indicated in the foregoing, it was not possible to either use this program as a load generator to a stress program or to generate traffic data. Further, most of the parameters required in the input were either unnecessary or related to the control of meaningless statistics generated by the original program. Subsequent to performing the major modifications discussed previously, it was then possible to identify meaningful parameters for the performance of sensitivity testing, or at least to be considered for sensitivity testing. It should be noted that the technique of sensitivity testing is a process of evaluating the effects of variables in a mathematical or logical model whose relationships in the model cannot be explained analytically. This is the case with representations that utilize engineering fudge factors or stochastic processes.

Potential Input Parameter Candidates

The input parameters which remained in the load generator subsequent to modification, were not traffic statistics, and which potentially could affect the output of the generator, were defined as follows:

NTH	Number of load samples, i.e., number of input cases to be run; it defaults to 1.
MD	Maximum number of vehicle types over a simulation run, i.e., all NTH spaces per run; it defaults to 11, with a maximum of 20 allowed.

LT	Number of class intervals for weight histograms; defaults to 12 equal intervals, with a maximum of 99 intervals.
NL	Number of lanes, i.e., bridge width in lanes. (No meaning of a 1 lane utilization presently. However, should be retained for future expansion to more than one lane.) It defaults to 2.
ND	Number of directions of traffic flow, if 1 then 2 lane unidirectional flow; if 2 then 2 lane bidirectional flow; defaults to 1.
NZ	Number of restricted or graded zones, $NZ \leq 5$, each are defined below; defaults to 0.
SIMTIM	Length of simulation time for given simulation case, minutes; defaults to program abort.
DELTIM	Interval of integration for solution of traffic motion, secs.
BRPOS	Center of bridge relative to the beginning of the roadway, establishes roadway approach length to the bridge. This value defaults to 1100 ft.
TALINC	Class interval for weight histograms collected over simulation times, lbs; defaults to 8000 lb. intervals.

ACCEL	Maximum acceleration allowed for any vehicle, fps^2; defaults to 15 f/sec^2.
SPDLIM	Highway speed limit, mph; defaults to 65 mph.
EXSPD	Excess speed permitted for passing, mph; defaults to 15 mph.
BRLEN	Bridge length for case to be run, normally should be of maximum length of interest. The structural program will allow the input of the actual bridge lengths to be analyzed which will be less than or equal to this value for the section of highway of interest; defaults to 200 feet.
SDFAC	Speed factor to determine maximum decision point for passing, ft-hr/mi, defaults to 15 which provides approximately one vehicle length per 10 mph speed.
SAFDIS	Minimum distance between vehicles, ft.; defaults to 10 ft.
TRKLIM	Truck speed limit, mph.; defaults to 55 mph.
SPDMIN	Minimum vehicle speed, mph.; defaults to 40 mph.

In evaluating the input parameters, two basic considerations were used as guidelines:

1. Preservation of the input traffic population statistics, on the bridge deck, and

2. Minimization of computer time for generating synthetic deck loads.

With these factors in mind, an initial analysis of all input parameters was performed to minimize the sensitivity testing. A subsequent computer based sensitivity test was performed on those parameters which remained in doubt as to their affects upon generated loads.

Analysis of the Candidate Parameters

The initial analysis of the above specified input parameters indicated the following:

1. NTH is a case count parameter that does not affect generated loads and did not require sensitivity testing.

2. MD is basically a traffic parameter based upon the categorization of truck types, all autos form one category, and is totally dependent upon the field collected population sample or an hypothesized sample. It did not require sensitivity testing.

3. LT is an output control value, i.e., it controls the number of class intervals in the weight histograms, but in no way affects the generated load data to be used by the stress program. It did not require sensitivity testing.

4. NL is the bridge width in lanes. The load generator is limited to a maximum of 2 lanes of either unidirectional traffic flow or bidirectional flow. At present a one-lane bridge has no meaning to the generator. Hence, it did not require sensitivity testing.

5. ND is the number of traffic flow directions. It did require testing for functional performance and a gross form of sensitivity testing, i.e.,was there a significant difference between unidirectional flow simulation and bidirectional flow simulation.

6. NZ is the restricted zone control number. This parameter definitely required evaluation. However, the related parameters e.g., restricted zone length, grade, etc., had to be simultaneously evaluated in terms of their impact upon the generated data and proper functional operation.

7. SIMTIM is the length of simulated time over which loads are continually generated. This variable required evaluation in terms of its impact upon the preservation of the stochastic parameters defining the traffic for any given highway. Desirably,the best value was that which adequately preserved the stochastic parameters and was the smallest in magnitude. Assuming normal distribution of each type of truck, in order to achieve a 90% confidence interval of the occurrance of the lowest incidence vehicle type, approximately a 5-hour simulation time is necessary for the stochastic parameters defined for the MD 301 bridge data contained in the original program.

8. DELTIM is the integration interval used in the solution of the motion of the vehicles by the load generator. A conservatively safe value of DELTIM for the purpose of maintaining proper vehicle dynamics is .5 seconds. A one second interval appears to provide a nominally safe value. However, the error in the simple numerical integration utilized in the modified program, Euler's and Trapezoidal, due to internal size required evaluation. The largest value which maintained the accuracy necessary and consistent with the smaller values should be selected. Two effects were considered:

a. Error in calculating vehicle motion dynamics

b. Variation in vehicle logical behavior which affected the generated bridge loads.

9. BRPOS establishes the length of the roadway used for traffic simulation by the load generator. It is actually measured from the beginning of the roadway to the center of the bridge. This parameter required evaluation to determine its affect upon the generated loads. The smallest value which best preserves the statistical parameters defining the truck and traffic population, input to the program should, was selected for use.

10. TALINC is an output control parameter which establishes the size of the weight histogram class intervals which are used to collect the weights of the vehicles generated on the bridge deck over the period of simulation. This parameter in no way affected the generated load data for the stress program and is merely a user preference for weight histogram output.

11. ACCEL is a limiting value on the acceleration allowed any vehicle synthesized. A maximum default value of 15 fps^2 was established based upon realistic short term accelerations developed by high performance automobiles. It was not considered necessary to test this parameter since a realistic limit can be established from real vehicle performance. There is an assumption inherent in this decision, i.e., that the generator adequately synthesizes the behavior and motion of highway traffic.
Many vehicle behavior characteristics have been simplified or ignored in BRIGLD1.

12. SPDLIM, this value should be established by a user as a function of the highway of which his bridge is a part. A default value of 65 mph. has been established for this parameter. No sensitivity testing was considered necessary for the same reasons as stated in 11., above.

13. EXSPD is the amount of excess speed allowed above SPDLIM for passing. Again, this parameter is a function of the particular highway and should be established by a user. A default value of 15 mph. was established in the program and no sensitivity testing was considered necessary for the same reasons as stated in 11., above.

14. BRLEN is the length of the pseudo bridge deck on which the generated traffic loads are captured, structured and passed to the stress program. This value should be selected by a user on the basis of potential re-use for the section of highway which is represented by the statistical traffic data input to the bridge. It should be

at least as long as the longest possible span, simple or continuous, whichever is greater, which may be needed on the represented section of highway. The data generated by the load generator for one span of a multi-span bridge may be re-used by the stress program for all spans of a given bridge and for spans of nearly all bridges on the same highway, provided the input statistical traffic data is valid, since the stress program separately discerns its own load events for any given, and specific, bridge length. A default value of 200 feet was established for this parameter. Because of the foregoing no sensitivity testing was necessary, i.e., it in no way affected the loads input to the stress program.

15. SDFAC is the safe distance factor between following vehicles. It is based upon the use of a gap between vehicles as a function of a following vehicle's speed. Using the rule of thumb of one vehicle length per 10 mph of speed, a default value of 15 was established for this parameter. The actual value for this rule of thumb is 14-2/3/sec. However, it is fairly well established that the desired safe following rule of thumb is not, in general, maintained. Hence, it was decided that the effect of this parameter upon the generated loadings should be determined so that, if any significant dependency existed, a user would have a basis of selecting an input value for this parameter as a function of traffic behavior on any given highway.

16. SAFDIS is the absolute minimum distance that a following vehicle may approach a leading vehicle. At reaching this distance with no other actions having occurred the program forces the following vehicle to either pass

or slow to the same speed as the leading vehicle. This parameter, is a lower limit and a function of traffic behavior on the given highway. A default value of 10 feet was established and no sensitivity testing was felt necessary for this parameter.

17. TRKLIM is the speed limit imposed upon trucks, actual or theoretical, for a given highway. If this value is set at the legal limit, then, EXSPD should be set realistically, i.e., on the basis of actual behavior of truck traffic speedwise. A default value of 55 mph was established for this parameter and sensitivity testing was not felt necessary.

18. SPDMIN is the nominal minimum speed anticipated or recorded for the given highway, adjacent to the bridge. It is established within the load generator program as an absolute minimum speed at which vehicles must travel. This was necessary because the BRIGLD1 simulator used an algorithm for vehicle speed which appeared to converge toward zero rather than the statistical nominal speed assigned to a vehicle as a steady state speed. Sufficient interaction of vehicles over a long, synthetic, roadway fails to continue at a high enough level for the interaction portion of the algorithm to force a maintenance of speed and since the algorithm does <u>not</u> converge upon the steady state speeds assigned, a trend toward zero speed occurs. It is essential that a value of SPDMIM be input to prevent this problem. Inhibition of this tendency is also accomplished by using a minimum acceptable roadway approach to the bridge. A default value of 40 mph. was established in the program.

Parameters to be Tested

As a result of the foregoing analysis,the set of parameters requiring sensitivity testing was established as:

1. ND - Number of flow directions

2. NZ - Number of restricted zones

3. SIMTIM - Simulation Time (Sec)

4. DELTIM - Time increment (Sec)

5. BRPOS - Length of approach roadway (plus 1/2 bridge length)(feet)

6. SDFAC - Safe distance factor

The implications of testing the above parameters was as follows:

1. The ND test was primarily a functional test and provided evidence of the ability of the BRIGLD1 generator to function in either a unidirectional or bidirectional manner.

2. NZ is merely a control parameter and did not directly imply anything of consequence. However, grade variation testing would indicate the ability of the generator to impose the effects of grades adjacent to a bridge. This test would merely indicate whether the load generator provided realistic effects from adjacent grades. The no-passing zone effect was of small consequence and

had significant meaning only in terms of bidirectional traffic flow.

3. SIMTIM required evaluation to determine the nominal minimum stable simulation time, which was defined as that simulation time sufficient to preserve the input statistical parameters.

4. The testing of DELTIM would indicate the most economic integration interval for calculating traffic motion.

5. The most economic, and stabilizing, highway approach length which preserved prescribed traffic statistics would be indicated by the testing of BRPOS.

6. The testing of SDFAC would provide indication of the sensitivity of this parameter and establish an estimate of a worst case value to utilize the default input purposes.

Parameter Test Order

In addition, there was a very definite interdependence of the above parameters. Hence, those parameters most dependent upon the others in the set would be tested last. Those least dependent upon the remainder of the set were tested first. The order of the testing performed was as follows:

1. BRPOS to determine minimum stable load generation approach length.

2. SIMTIM to determine minimum characterizing simulation time.

3. DELTIM to determine maximum practical interval of motion integration.

4. SDFAC to determine worst case value for default purposes and significance of this variable.

5. NZ to determine significance and validity of synthesized grade effects.

6. ND to determine the sensitivity of this variable in the load generator, and its functional behavior.

Sensitivity Test Specification

As a result of all of the analysis previously described, a specification of the "sensitivity" testing to be performed was developed at the point in the project where the BRIGLD1 simulator was as well debugged as could be determined for unidirectional flow traffic.

The tests were specified as follows:

1. ND - Number of directions of traffic flow

a. Test bidirectional flow to assure valid simulation.

b. Run one bridge configuration for uni- and bidirectional traffic flow, based upon the same highway traffic data base. This was necessary due to the

form of BRIGLD1. It was anticipated that the bidirectional flow would produce a higher incidence of loading events and tend toward a worst case loading, as compared to the unidirectional flow. Thus, a synthetic bidirectional flow would produce more significant input for the structural program. Constant approach lengths and the best set of parameters from previous tests were utilized in this test.

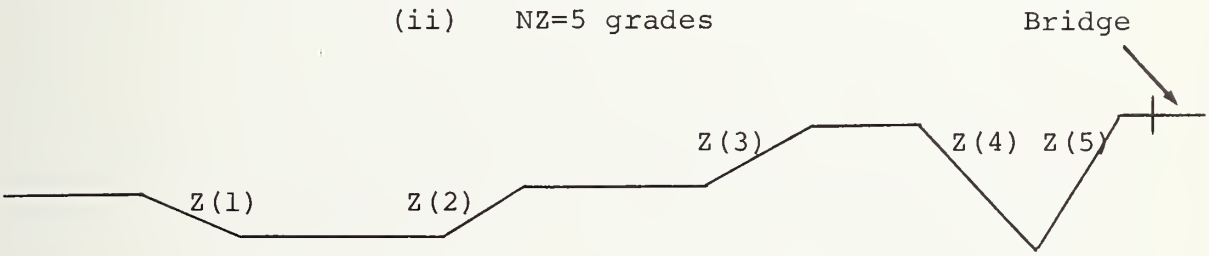
2. NZ - NZ would be tested for one bridge configuration, for a minimum valid simulation period, and for the following cases, with the best set of parameters from previous tests:

a. For functional and accuracy testing:

(1) Unidirectional 2 lane flow for

(i) NZ=0

(ii) NZ=5 grades

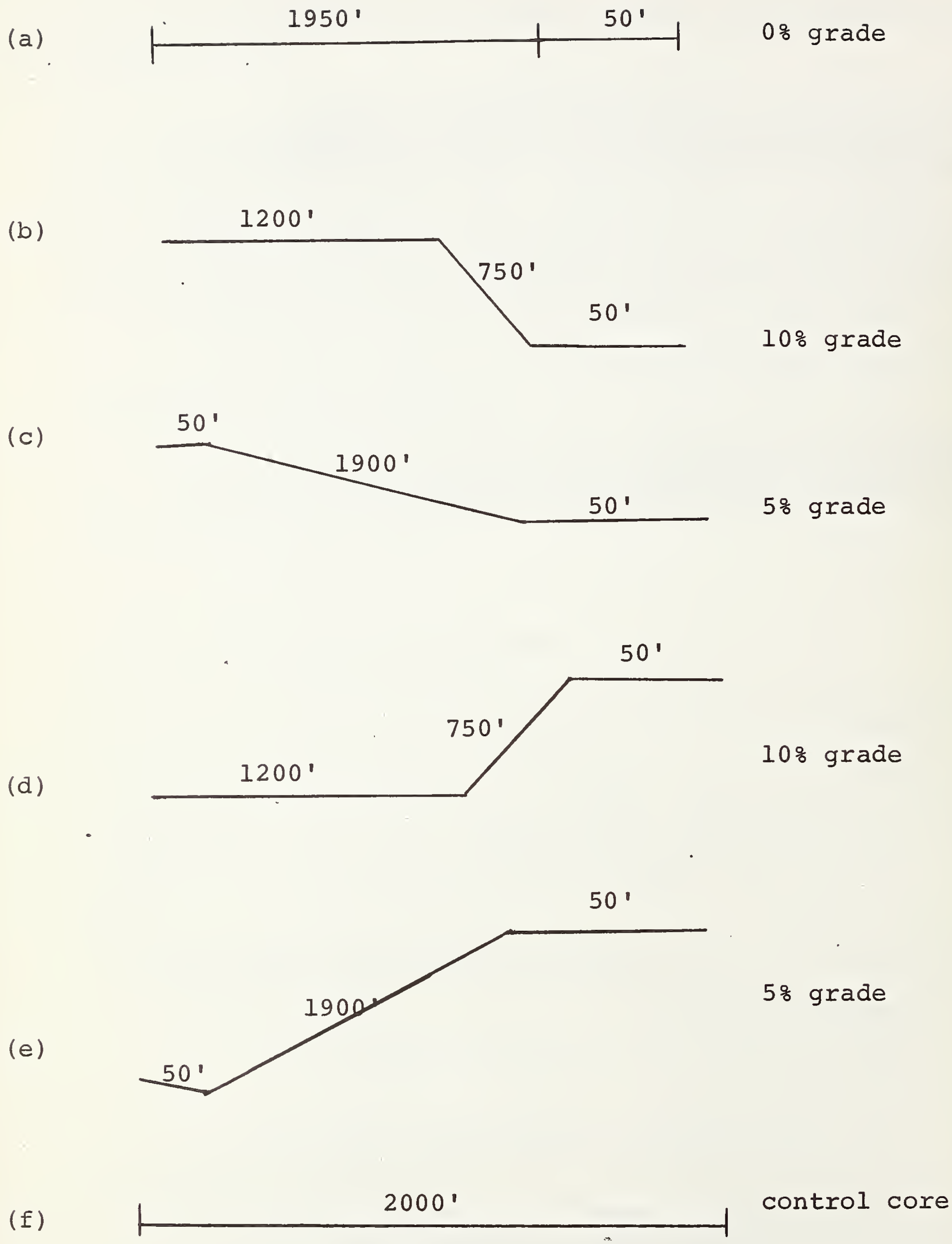


(2) Bidirectional flow for 2 lanes for

(i) NZ=0

(ii) NZ=5 (as above)

(iii) NZ=1 for z(1) = 0


(a)
1950'
50'
0% grade
(b)
1200'
750'
50'
10% grade
(c)
50'
1900'
50'
5% grade
(d)
50'
750'
1200'
10% grade
(e)
50'
1900'
50'
5% grade
(f)
2000'
control core

3. SIMTIM - SIMTIM would be either tested or analytically determined such that the minimum simulation time preserved the input traffic statistics. Probability analysis of available data indicated approximately 5 hours to provide a 90% confidence.

4. DELTIM - DELTIM would be tested as follows:

For maximum anticipated bridge length, run, 250 ft.,

a. .5 sec.
b. 1.0 sec.
c. 1.5 sec.
d. 2.0 sec.

It was anticipated that 1.0 sec. integration intervals will be near optimum for all conditions. Use a constant stable approach length and a valid simulation time, as indicated from prior testing would be used.

5. BRPOS - BRPOS would be tested for one, nominal, bridge length and allowed to vary to determine statistical variations of truck loads approaching on the bridge. This would be done as follows:

For a fixed SIMTIM, Δt = 1.0 sec., and uni-directional traffic flow, as:

a. 26,400 ft., 5 miles
b. 10,560 ft., 2 miles
c. 4,000 ft.

d. 1,000 ft.

e. 200 ft.

6. SDFAC - SDFAC would be tested for unidirectional traffic flow, constant approach length, constant bridge length, for constant highway, for values of

a. 5

b. 10

c. 15 (default value)

d. 20

e. 25

using the best set of parameters from prior testing.

Conduct and Results of Tests

In accordance with the previously presented test specification, the sensitivity tests were conducted, after review and concurrence by the Government's Contract Monitor of the specification. The testing and the results are described within this section of the report.

It should be noted that this testing effort was the first, essentially, production type use of the program and numerous difficulties were encountered in achieving a "production" mode. These problems were of the nature of structuring the JCL to accommodate "production" runs of the program. Two problems, bugs, were encountered during the testing, i.e.,

1. Failure of the program to run with extremely short roadway approaches. This was quickly and easily corrected.

2. Difficulty in getting reasonably valid bidirectional traffic flow. This was an unanticipated problem. Since the original BRIGLD1 simulator was supposed to provide valid synthesis of bidirectional flow. However, this was consistent with the difficulties encountered in making the simulator simulate, as discussed earlier in this report.

BRPOS Testing - Much emphasis was laid upon the need to provide a sufficient roadway length, i.e., the approach (es) to the bridge deck, in the original BRIGLD1 report (1) The basis of this emphasis was the need to provide adequate simulation time, prior to bridge entry, to develop a stable traffic behavior, i.e., to overcome the effects of the pseudo-random generator algorithm. However, a detailed evaluation of the pseudo-traffic behavior indicates that for the traffic population, and characteristics utilized, i.e., the same as the original work, Md. 301, the traffic synthesis appeared realistic after a very short distance. The use of long roadway approaches earlier evidenced the tendency of the simulator to converge to a zero speed and resulted in the establishment of a minimum speed to inhibit this tendency. However, the simulator still behaves in this fashion and with long roadway approaches will tend for all vehicles to converge on first the steady state speed, and second, on the minimum speed. Further, dynamic interaction of the vehicles appears to damp out. This is definitely a handicap because of the established relationship of speed and weight to bridge structural responses. Further, the preservation of the given highway traffic statistics fails to be preserved for long roadway approaches.

The evaluation criterion was:

1. Preservation of original traffic statistics on the bridge deck, i.e., captured loading data,

2. Minimum roadway length, for economization of computer time, and

3. Normalization of traffic behavior from initial generation state, especially representative distribution into the second lane for the unidirectional flow.

Summaries of the results of the BRPOS tests are shown in Tables 1. through 7. Tables 1. through 5. reflect the main test parameters, for each roadway approach length, and comparisons of prescribed truck incidence, i.e., the input distribution function, versus the truck population sample captured on the bridge deck. These tables also contain the comparisons of the given platoon distribution function versus the platoon population generated and versus the platoon population captured on the bridge deck. The platoon distribution function utilized was purely theoretical and was a binary distribution function. No data on the incidence of various platoon sizes over a given length of roadway was found to provide an experimental basis. The binary distribution function was used for testing purposes. However, a theoretical basis for its use can be developed to support interim use of the function.

Table 6 provides a comparison of the variations, in percent, of the truck population captured on the deck versus the given truck population. The mean variation, in percent, of each roadway length, extracted from Table 6, is as follows:

TABLE 1 - 200 Ft. Roadway Approach Test

Test Parameters

Bridge Length: 200 Ft. Δt: 1 Sec. Simulated Time: 1800 Sec.

Generated Parameters

Vehicles Generated	Trucks Generated	Approach Time	Computer Time
964	159	3 Sec.	32 Sec.

TRUCK INCIDENCE

Vehicle Type	2	3	4	5	6	7	8	9	10	11	TOT
Given (%)	4.50	1.00	.30	.30	.30	1.20	1.30	3.40	3.40	1.20	
Bridge (#)	42	10	3	0	3	12	10	31	33	15	159
Capture (%)	4.49	1.07	.32	.00	.32	1.28	1.07	3.31	3.53	1.60	

PLATOON INCIDENCE

Platoon Size	1	2	3	4	5	6	7	8	9	10	11	12	13	TOT
Given (#)	42.5	21.25	10.62	5.31	2.66	2.65	-	-	-	-	-	-	-	85
(%)	50.0	25.0	12.5	6.25	3.13	3.12	-	-	-	-	-	-	-	
Generated (#)	44	24	6	8	1	2	-	-	-	-	-	-	-	85
(%)	51.8	28.2	7.1	9.4	1.2	2.3	-	-	-	-	-	-	-	
Bridge (#)	27	22	9	4	4	2	0	0	0	0	0	0	1	69
Capture	39.1	31.9	13.0	5.8	5.8	2.9	0	0	0	0	0	0	1.5	

TABLE 2 - 1000 Ft. Roadway Approach Test

Test Parameters

Bridge Length: 200 Ft. Δt: 1 Sec. Simulated Time: 1800 Sec.

Generated Parameters

Vehicles Generated	Trucks Generated	Approach Time	Computer Time
970	163	14 Sec.	37 Sec.

TRUCK INCIDENCE

Vehicle Type												
Given (%)	83.00	4.50	1.00	.30	.30	.30	1.20	1.30	3.40	3.40	1.20	
Bridge (#)	*	42	10	3	0	3	12	10	31	33	15	159
Capture (%)	*	4.49	1.07	.32	.00	.32	1.28	1.07	3.31	3.56	1.60	

PLATOON INCIDENCE

Platoon Size										
Given (#)	43	21.5	10.75	5.38	2.69	2.69	-	-	-	86
(%)	50	25.00	12.50	6.25	3.13	3.12	-	-	-	
Generated (#)	44	24	6	9	1	2	-	-	-	86
(%)	51.2	27.9	7.0	10.5	1.2	2.2	-	-	-	
Bridge (#)	40	17	9	7	3	1	0	0	1	78
Capture (%)	51.3	21.8	11.5	9.0	3.8	1.3	0.0	0.0	1.3	

TABLE 3 - 4000 Ft. Roadway Approach Test

Test Parameters

Bridge Length: 200 Ft. Δt: 1 Sec. Simulated Time: 1800 Sec.

Generated Parameters

Vehicles Generated	Trucks Generated	Approach Time	Computer Time
990	167	48 Sec.	69 Sec.

TRUCK INCIDENCE

Vehicle Type	2	3	4	5	6	7	8	9	10	11	TOT.
Given (%)	4.50	1.00	.30	.30	.30	1.20	1.30	3.40	3.40	1.20	
Bridge (#)	42	10	3	0	3	12	9	31	33	15	158
Capture (%)	4.52	1.08	.32	.00	.32	1.29	.97	3.34	3.55	1.61	

PLATOON INCIDENCE

Platoon Size	1	2	3	4	5	6	7	8	9	TOT.
Given (#)	44.5	22.2	11.1	5.6	2.8	2.8	-	-	-	89
(%)	50.0	25	12.50	6.2	3.1	3.1	-	-	-	
Generated (#)	46	25	6	9	1	2	-	-	-	89
(%)	51.7	28.1	6.7	10.1	1.1	2.3				
Bridge (#)	49	25	7	6	0	1	0	1	0	89
Capture (%)	55.0	28.1	7.9	6.8	0.0	1.1	0.0	1.1	0	89

TABLE 4 - 10,560 Ft. Roadway Approach Test

Test Parameters

Bridge Length: 200 Ft.

Δt: 1 Sec.

Simulated Time: 1800 Sec.

Generated Parameters

Vehicles Generated	Trucks Generated	Approach Time	Computer Time
1028	172	118 Sec.	137 Sec.

TRUCK INCIDENCE

Vehicle Type											
Given (%)	4.50	1.00	.30	.30	.30	1.20	1.30	3.40	3.40	1.20	
Bridge (#)	41	10	3	0	3	12	9	30	32	15	155
Capture (%)	4.38	1.07	.32	.00	.32	1.28	.96	3.21	3.42	1.60	

PLATOON INCIDENCE

Platoon Size														
Given (#)	45.5	22.75	11.38	5.69	2.84	2.84	-	-	-	-	-	-	-	91
(%)	50.0	25.0	12.5	6.25	3.13	3.12	-	-	-	-	-	-	-	
Generated (#)	46	26	7	9	1	2	-	-	-	-	-	-	-	91
(%)	50.5	28.6	7.7	9.9	1.1	2.2	-	-	-	-	-	-	-	
Bridge (#)	38	20	5	6	3	0	2	0	1	-	-	-	-	75
Capture (%)	50.7	26.7	6.7	8.0	4.0	0.0	2.7	0	1.3	-	-	-	-	

TABLE 5 - 26,400 Ft. Roadway Approach Test

Test Parameters

Bridge Length: 200 Ft.	Δt: 1 Sec.	Simulated Time: 1800 Sec.

Generated Parameters

Vehicles Generated	Trucks Generated	Approach Time	Computer Time
1117	181	287 Sec.	315 Sec.

TRUCK INCIDENCE

Vehicle Type	2	3	4	5	6	7	8	9	10	11	TOT.
Given (%)	4.50	1.00	.30	.30	.30	1.20	1.30	3.40	3.40	1.20	
Bridge (#)	36	9	2	0	3	12	8	30	32	14	.46
Capture (%)	4.19	1.05	.23	0	.35	1.40	.93	3.49	3.73	1.63	

PLATOON INCIDENCE

Platoon Size	1	2	3	4	5	6	7	8	9	TOT.
Given (#)	48	24	12	6	3	3	-	-	-	96
(%)	50.0	25.0	12.5	6.25	3.13	3.12	-	-	-	
Generated (#)	49	26	9	9	1	2	-	-	-	96
(%)	51.0	27.1	9.4	9.4	1.0	2.1	-	-	-	
Bridge (#)	29	13	5	8	4	0	1	1	1	62
Capture (%)	46.8	21.0	8.1	12.9	6.4	0	1.6	1.6	1.6	

TABLE 6 - Variation From Given Traffic Population Distribution

Type / Approach	2	3	4	5	6	7	8	9	10	11	Av. Ave. Var.	From Generated Total Sample
200 Ft.	-.01	.07	.02	.3	.02	.08	-.23	-.09	.13	.40	.14	0
1000 Ft.	-.01	.07	.02	.3	.02	.08	-.23	-.09	.16	.40	.14	-4
4000 Ft.	.02	.08	.02	.3	.02	.09	-.33	-.06	.15	.41	.15	-9
10,560 Ft.	-.12	.07	.02	.3	.02	.08	-.34	-.19	.02	.40	.16	-16
26,400 Ft.	-.31	.05	-.07	.3	.05	.20	-.37	.09	.33	.43	.22	-35
Mean Abs Variation	.02	.07	.03	.3	.026	.106	.3	.104	.158	.408	.15	12.8

TABLE 7 - Variation From Given Platoon Distribution

Platoon Size Platoon Size	1	2	3	4	5	6	7	8	9	10	11	12	13	From Gener-ated Total Sample
Approach														
200 Ft.	-10.9	6.9	.5	-.5	2.7	-.2	-	-	-	-	-	-	1.5	-16
1000 Ft.	1.3	03.2	-1.0	2.7	.7	-1.8	-	-	1.3	-	-	-	-	-8
4000 Ft.	5.0	3.1	-4.6	.6	-3.1	-2.0	-	1.1	-	-	-	-	-	0
10,560 Ft.	.7	1.7	-5.8	1.8	.9	-3.1	2.7	-	1.3	-	-	-	1.5	-16
26,400 Ft.	-3.2	-4.0	-7.6	6.7	3.3	-3.1	1.6	1.6	1.6	-	-	-	-	-34
Mean Abs Variation	4.2	3.8	3.9	2.5	2.1	2.0	.86	.54	.84	-	-	-	.6	15

Approach Length	Mean Variation
200'	.12%
1,000'	.12%
4,000'	.13%
10,560'	.14%
26,400'	.20%

while the mean absolute variation, in percent, from Table 6, is .14%. The above data implies that the two shorter roadway lengths better preserve prescribed platoon distribution functions than the longer roadway approach lengths.

The mean variation, in percent, of each roadway length, extracted from Table 7., is as follows:

Approach Length	Mean Variation
200'	3.9%
1,000'	2.0%
4,000'	3.25%
10,560'	3.25%
26,400'	5.45%

while the mean absolute variation, in percent, from Table 7., is 3.56%. The above data implies that the 1,000 foot roadway approach preserves specified platoon distributions for a given highway better than the other tested roadway approach lengths. The next two best roadway lengths were 4,000 feet and 10,560 feet.

As a result of the aforementioned tests, it is obvious that short roadway approach lengths, BRPOS, are better for use with the simulator. Of the above lengths listed, 1,000 feet gave the best results.

The reason for the poor showing of the longer approach lengths, while intuitively they would appear to be better candidates for providing stable traffic behavior, is due to the degradation of the simulation algorithm over long roadways. This problem has been discussed elsewhere in this report. Briefly, the algorithm first converges to the vehicle steady state speed, initially generated in the pseudo-random process and second converges on a zero speed, without a lower limit imposed. In order to utilize the program a value of BRPOS must be selected which allows sufficient simulation time, to the bridge, for dynamic traffic behavior to propagate and for a distribution into the second lane to occur, as a lower limit, prior to any degradation of the performance of the vehicles.

The tests described herein, then, indicate that an upper limit on BRPOS exists wherein the simulator fails to simulate properly.

Some dependency may exist on the given highway statistical data. However, this should not be a strong tendency unless the population is extremely small. In general, select BRPOS as follows:

$$200 \text{ feet} \leq (\text{BRPOS} - \text{BRLEN}) \leq 4{,}000 \text{ feet}$$

An initial value of 1,000 feet, plus one-half the bridge length, should be used for any new application until evidence indicates that a better value exists.

It should be noted that this tendency of the simulator is a fortunate one, since shorter computer execution times are implied by lower values of BRPOS, e.g., from Tables 1 through 5.

Approach Length	Computer Execution Time
200'	32 sec.
1,000'	37 sec.
4,000'	69 sec.
10,560'	137 sec.
26,400'	315 sec.

SIMTIM Testing - Upon completion and quick analysis of the results of the BRPOS tests, a value of 1,000 feet for roadway external to the bridge was selected for this test. All other parameters were held at the same values as utilized in the BRPOS tests.

Prior to specifying the SIMTIM test an estimate of the length of simulation time necessary to provide a 90% confidence interval that at least one occurrance of each type vehicle would happen, based upon the given truck population distribution function. This led to a value of approximately five hours of simulated time. Also, the previous test had used one-half hour as a simulation period and achieved reasonable results. Hence, the test was specified as previously defined and conducted as specified.

TABLE 8 - One Hour Simulation Time Test

Test Parameters

Bridge Length: 200 Ft. | Δt: 1 Sec. | Approach Length: 1000 Ft.

Generated Parameters

Vehicles Generated	Trucks Generated	Approach Time	Computer Time
1879	308	14 Sec.	22 Sec.

Vehicle Incidence

Vehicle Type	1	2	3	4	5	6	7	8	9	10	11	Total
Given (%)	83.0	4.5	1.0	.3	.3	.3	1.2	1.3	3.4	3.4	1.2	
Bridge (#)	1572	91	15	4	4	6	22	16	60	57	29	1876
Capture (%)	83.8	4.85	.8	.21	.21	.32	1.17	.85	3.2	3.04	1.55	
Variation	.8	.35	-.2	-.09	-.09	.02	-.03	-.45	-.2	-.36	.35	

Platoon Incidence

Platoon Size	1	2	3	4	5	6	7	8	9	Total
Given (#)	79.5	39.8	19.9	9.9	5.0	2.5	-	-	-	159
(%)	50.0	25.0	12.5	6.25	3.13	3.12				
Generated (#)	81	41	16	12	5	4	-	-	-	159
(%)	50.9	25.8	10.1	7.5	3.2	2.5	-	-	-	
Bridge (#)	69	32	13	14	8	4	-	-	1	141
Capture (%)	48.9	22.7	9.2	9.9	5.7	2.8	-	-	.7	
Variation	-1.1	-2.3	-3.3	3.65	2.57	-.55	-	-	.7	

TABLE 9 - Two & One Half Hour Simulation Time Test

Test Parameters

Δt: 1 Sec.

Bridge Length: 200 Ft. Approach Length: 1000 Ft.

Generated Parameters

Vehicle Generated	Trucks Generated	Approach Time	Computer Time
4600	717	14 Sec.	51 Sec.

VEHICLE INCIDENCE

Vehicle Type	1	2	3	4	5	6	7	8	9	10	11	Tot.
Given (%)	83.0	4.5	1.0	.3	.3	.3	1.2	1.3	3.4	3.4	1.2	
Bridge (#)	3877	214	37	12	11	17	47	41	143	139	56	4594
Capture (%)	84.4	4.6	.8	.3	.2	.4	1.0	.9	3.1	3.0	1.2	
Variation	1.4	.1	-.2	.0	-.1	.1	-.2	-.4	-.3	-.4	0.0	

PLATOON INCIDENCE

Platoon Size	1	2	3	4	5	6	7	8	9	10	Tot.
Given (#)	179.5	89.8	44.9	22.4	11.2	11.2	-	-	-	-	359
(%)	50.	25.	12.5	6.2	3.1	3.1	-	-	-	-	
Generated (#)	177	93	42	21	12	14	-	-	-	-	359
(%)	49.3	25.9	11.7	5.8	3.3	3.9					
Bridge (#)	157	74	39	24	18	11	2	1	2	-	328
Capture (%)	47.9	22.6	11.9	7.3	5.5	3.3	.6	.3	.6	-	
Variation	-2.1	-2.4	-.6	1.1	2.4	.2	.6	.3	.6	-	

TABLE 10 - Four Hour Simulation Time Test

Test Parameters

Bridge Length: 200 Ft. Δt: 1 Sec. Approach Length: 1000 Ft.

Generated Parameters

Vehicles Generated	Trucks Generated	Approach Time	Computer Time
7327	1156	14 Sec.	82 Sec.

VEHICLES INCIDENCE

Vehicle Type	1	2	3	4	5	6	7	8	9	10	11	Total
Given (%)	83.0	4.5	1.0	.3	.3	.3	1.2	1.3	3.4	3.4	1.2	
Bridge (#)	6166	318	63	18	20	28	79	79	229	236	86	7323
Capture (%)	84.2	4.3	.9	.2	.3	.4	1.1	1.1	3.1	3.2	1.2	
Variation	1.2	-.2	-.1	-.1	.0	.1	-.1	-.2	-.3	-.2	.0	

PLATOON INCIDENCE

Platoon Size	1	2	3	4	5	6	7	8	9	10	Total
Given (#)	295.5	147.8	73.9	36.9	18.5	18.5	-	-	-	-	
(%)	50.0	25.0	12.5	6.2	3.1	3.1	-	-	-	-	
Generated (#)	299	145	76	35	17	19	-	-	-	-	591
(%)	50.6	24.5	12.8	5.9	2.9	3.2	-	-	-	-	
Bridge (#)	254	114	66	43	29	12	3	1	5	1	528
Capture (%)	48.1	21.6	12.5	8.1	5.5	2.3	.6	.2	.9	.2	
Variation	-1.9	-3.4	0.0	1.9	2.4	-.8	.6	.2	.9	.2	

TABLE 11 - Five Hour Simulation Time Test

Test Parameters

Bridge Length: 200 Ft. Δt: 1 Sec. Approach Length: 1000 Ft.

Generated Parameters

Vehicles Generated	Trucks Generated	Approach Time	Computer Time
9192	1495	14 Sec.	102 Sec.

VEHICLE INCIDENCE

Vehicle Type	1	2	3	4	5	6	7	8	9	10	11	Total
Given (%)	83.0	4.5	1.0	.3	.3	.3	1.2	1.3	3.4	3.4	1.2	
Bridge (#)	7692	407	85	24	30	34	96	103	294	310	111	9186
Capture (%)	83.7	4.4	.9	.3	.3	.4	1.0	1.1	3.2	3.4	1.2	
Variation	.7	-.1	-.1	0.0	0.0	.1	-.2	-.2	-.2	0.0	0.0	

PLATOON INCIDENCE

Platoon Size	1	2	3	4	5	6	7	8	9	10	
Given (#)	376.5	188.2	94.1	47.1	23.5	23.5	-	-	-	-	753
(%)	50.0	25.0	12.5	6.2	3.1	3.1	-	-	-	-	
Generated (#)	373	187	98	46	24	25	-	-	-	-	753
(%)	49.5	24.8	13.0	6.1	3.2	3.3	-	-	-	-	
Bridge (#)	318	143	88	58	36	14	4	2	8	1	672
Captive (%)	47.3	21.3	13.1	8.6	5.4	2.1	.6	.3	1.2	.1	
Variation	-2.7	-3.7	.6	2.4	2.3	-1.0	.6	.3	1.2	.1	

TABLE 12 - Ten Hour Simulation Time Test

Test Parameters

Bridge Length: 200 Ft. — Δt: 1 Sec. — Approach Length: 1000 Ft.

Generated Parameters

Vehicles Generated	Trucks Generated	Approach Time	Computer Time
18,460	2892	14 Sec.	204 Sec.

VEHICLE INCIDENCE

Vehicle Type	1	2	3	4	5	6	7	8	9	10	11	Tot.
Given (%)	83.0	4.5	1.0	.3	.3	.3	1.2	1.3	3.4	3.4	1.2	
Bridge (#)	15,564	777	177	50	50	61	202	185	590	582	215	18,453
Capture (%)	84.3	4.2	1.0	.3	.3	.3	1.1	1.0	3.2	3.2	1.2	
Variation	1.3	-.3	0.0	.0	.0	.0	-.1	-.3	-.2	-.2	0.0	

PLATOON INCIDENCE

Platoon Size	1	2	3	4	5	6	7	8	9	10	Total
Given (#)	736	368	184	92	46	46	-	-	-	-	1472
(%)	50.0	25.0	12.5	6.2	3.1	3.1	-	-	-	-	
Generated (#)	758	359	165	86	47	57	-	-	-	-	1472
(%)	51.5	24.4	11.2	5.8	3.2	3.9	-	-	-	-	
Bridge (#)	698	300	166	91	65	32	9	4	8	4	1377
Capture (%)	50.7	21.8	12.0	6.6	4.7	2.3	.7	.3	.6	.3	
Variation	.7	-3.2	-.5	.4	1.6	-.8	.7	.3	.6	.3	

Similar to the previous test, this test should be evaluated upon the basis of preservation of given input, traffic statistics. Tables 8 through 12 present the variations in percent, from the given statistics for total traffic population and for distribution of platoon size. Theoretically, the longer the simulation time, i.e., the larger the sample, the closer the generated statistics converge upon the given statistics. It was not felt necessary to compare the generated traffic population data since its content remained invariant. However, the generated platoon size data was included in order to evaluate maintenance of the given platoon statistics at the point of generation. Further, it was seen that the traffic simulation superimposed a platoon stringing effect which was a function of the pseudo bridge length. This was evidenced by the occurrence of platoon sizes larger than those generated. It was due to the definition of a bridge platoon used in the simulator, as previously discussed. As the pseudo bridge length grew longer, the size of a platoon increased. Conversely, as the pseudo bridge length grew shorter, the size of a bridge platoon decreased. This was further impacted by the simulator logic and data interface requirements to the stress analysis program. The simulator continued a truck platoon event beyond the actual existence of a truck axle within the pseudo bridge length. Any truck axle that would appear on the pseudo bridge within the next time increment acted to continue the event. Hence, at maximum acceptable speed the pseudo bridge length was artifically extended approximately 100 feet. In the test cases reported on, the platoon defining distance became, in the worst case, approximately 300 feet. Thus the platoon statistics determined within

the pseudo bridge length reflected the existence of truck separation distances, i.e., between rear and front axles of following trucks, ranging from approximately 20 feet to approximately 300 feet for the test cases. This had no material effect upon the prediction of the stress dynamics The stress analysis program defines its own truck platoon event based upon a steady-state through load-state to steady-state behavior of all points evaluated on the bridge. Thus a platoon event specified by the simulator was purposely defined, conservatively, to contain structural dynamic platoon events such that they were not arbitrarily destroyed or modified due to any simulator mechanisms.

The above, then, tended to disqualify the bridge captured platoon size statistics as a valid means of assessing a "best" SIMTIM value. This left the overall, gross, population statistics and the generated platoon statics preservation on the bridge to be evaluated against the given input statistical data. Table 13 reflects a comparison of the statistics for the values of SIMTIM used in the testing. As indicated above, the longer the simulation time, theoretically, the better the representation of the given statistics should become. However, a rather strange behavior of the simulator was evidenced in the data shown in Tables 8 through 13. The theoretically anticipated improvement was evidenced in the decrease of variation from the given distributions from a one hour value through the five hour value, but the ten hour value suddenly provided a poorer representation of the given distributions. This behavior was evidenced in both the generated traffic population distribution and the generated platoon size distribution data. The cause of this degradation at a ten hour simulated time was not investigated in depth due to the constraint imposed by other work remaining to be accomplished and the limitations of funds and time.

TABLE 13 - Variation Comparison

Bridge Capture Vehicle Incidence Variation From Given Distribution

SIMTIM	Vehicle Type 1	2	3	4	5	6	7	8	9	10	11	Absolute Average Variation
1 Hour	.8	.4	-.2	-.1	-.1	.0	-.0	-.4	-.2	-.4	.4	.3
2 1/2 Hours	1.4	.1	-.2	.0	-.1	.1	-.2	-.4	-.3	-.4	0.0	.3
4 Hours	1.2	-.2	-.1	-.1	.0	.1	-.1	-.2	-.3	-.2	.0	.2
5 Hours	.7	-.1	-.1	0.0	0.0	.1	-.2	-.2	-.2	.0 .0	.0	.1
10 Hours	1.3	-.3	.0	0.0	0.0	0.0	-.1	-.3	-.2	-.2	.0	.2
Av. Abs. Variation	1.08	.2	.1	.0	.0	.1	.1	.3	.2	.2	.1	.2

TABLE 13 - (Cont'd) Variation Comparison

Bridge Capture Platoon Incidence Variation From Given Distribution

Platoon Size	Given Platoons										Absolute Average Variation
SIMTIM	1	2	3	4	5	6	7	8	9	10	
1 Hour	-1.1	-2.3	-3.3	3.6	2.6	-.6	.0	.0	.7	.0	2.4
2 1/2 Hours	-2.1	-2.4	-.6	1.1	2.4	.2	.6	.3	.6	.0	1.7
4 Hours	-1.9	-3.4	.0	1.9	2.4	-.8	.6	.2	.9	.2	2.0
5 Hours	-2.7	-3.7	.6	2.4	2.3	-1.0	.6	.3	1.2	.1	2.5
10 Hours	.7	-3.2	-.5	.4	1.6	-.8	.7	.3	.6	.3	1.5
Average Abs. Var.	1.7	3.0	1.0	1.9	2.3	.7	.5	.2	.8	.1	2.0

TABLE 13 (Cont'd) - Variation Comparison

Generated Platoon Incidence Variation From Given Distribution

Platoon Size	1	2	3	4	5	6	Absolute Average Variation
1 Hour	.9	.8	-2.4	1.2	.1	-.6	1.0
2 1/2 Hrs.	-.7	.9	-.8	-.4	.2	.8	.6
4 Hours	.6	-.5	.3	-.3	-.2	.1	.3
5 Hours	-.5	-.2	.5	-.1	.1	.2	.3
10 Hours	1.5	-.6	-1.3	-.4	.1	.8	.9
Av. Abs.Var.	.8	.6	1.1	.5	.1	.5	.6

This could represent another very serious handicap in the use of the BRIGLD1 simulator as a synthetic bridge load generator. Since future use of this generator was predicated on taking time slice samples of approximately 2 weeks, 336 hours of simulated time, as a representative sample of a longer period, e.g., ten years, and repetition of this for a longer total bridge life span, e.g., fifty years, the above encountered problem bears significant investigation prior to such use.

The authors believe that the basis of this problem arose from the misuse of the pseudo-random number generating subroutine. It is used up to a maximum of six calls in the generation of a truck event, i.e., to propagate up to six separate and independent random functions. In the case of the ten hour test, this implied the generation of a maximum of 110,760 pseudo random numbers. This in itself is not a serious problem. However, all of these numbers, for six separate and independent functions, are generated from the same series and initiated by a single seed. It is strongly recommended, prior to extended use of this load generator, that six separate seeds be utilized, and maintained, one for each function. Further, each of the six series should be periodically re-initiated with new seeds.

It should be noted that the original version of this program did not provide for user initiation of even the single seed. This caused the program to always generate the same vehicle events in the same order.

In terms of preserving the given traffic population statistics and the platoon size statistics the five hour simulation time provided the best results. However, a five hour run is not an adequate sample for long term purposes.

DELTIM Testing - Since the variation of DELTIM (Δt) relates primarily to the integration of the differential equations of motion, it could only be evaluated in terms of the accuracy of vehicle motion synthesis. However, in this particular problem, i.e., bridge loading, the motion was of lesser consequence than the representation of the loadings on a bridge deck. Since no control data exists, i.e., field data on how any given bridge deck is loaded over any significant period of time, there was no direct comparative test available.

Further, analyzing the motion behavior of a large set of vehicles in a detailed accuracy evaluation of motion behavior is beyond the scope of this effort. A compromise evaluation approach for this parametric test was utilized. For the four cases run a comparison at simulation times common to all cases was made. The comparison was in terms of

1. Commonality of deck loading vehicle set

2. Sequence retention of the vehicles forming the set

3. Relative position of the specific vehicles in the set.

This analysis was then, essentially, based upon determining

1. Similarity of the truck load events generated

2. Occurrence of the events at the same time.

It was necessary to assume the Δt = .5 sec. as a reference, or control case. This value of Δt was small enough to prevent the overshooting of any logical operation performed by the simulator in synthesizing traffic behavior. Hence, all represented traffic behavior functions, within the simulator, should have occurred properly with this value.

The test parameters, and the test cases, utilized were as follows:

1. Traffic distribution data for Md. 301

2. A binary platoon distribution at generation

3. SIMTIM = 5.0 hours

4. Print-out of deck loads = 1.0 hour

5. Bridge length = 250 ft.

6. Roadway length = 1000 ft.

7. Δt variations were:

   Case #1 = .5 sec.
   Case #2 = 1.0 sec.
   Case #3 = 1.5 sec.
   Case #4 = 2.0 sec.

8. Data evaluation limited to 1/2 hour of bridge loading data at comparison values of time.

The reason for limiting the detailed bridge load data output to one hour was due to the extremely large quantity of output and the difficulties in arranging for the generation of such a large amount of printing. System constraints further created difficulties in the generation of these large quantities of output.

Basic data generated by the test cases is shown in Table 14. It should be noted that the characteristic of stringing smaller platoon sizes together to form a larger platoon also was true of larger integrating intervals, as is indicated in Table 14. This again was directly due to the definition of a platoon event utilized within the simulator, as discussed previously.

The analysis of the results are ordered in the following manner:

1. DELTIM - 1.5 sec. vs. .5 sec.

2. DELTIM - 2.0 sec. vs. .5 sec.

3. DELTIM = 1.0 sec. vs. .5 sec.

The above order was due to the order in which the test case results were produced, from the computer, and for no other reason.

Calculationally there is no difference, i.e., at most $\pm$ .01 feet, in the use of $\Delta t = 1.5$ versus 0.5 where the event is exactly the same on the bridge deck. This implies

TABLE 14 - Generated DELTIM Test Data

DELTIM		0.5 Sec.	1.0 Sec.	1.5 Sec.	2.0 Sec.	Sample Time
Platoons Generated		140	130	120	111	3600 Sec.
Vehicles Generated		-	9192	9192	9191	18,000 Sec.
Trucks Generated		-	1500	1500	1499	18,000 Sec.
Captured Platoons	Platoon Size					3600 Sec.
	1	70	61	53	41	
	2	30	23	23	26	
	3	12	17	16	13	
	4	14	13	9	11	
	5	9	9	10	10	
	6	3	5	4	6	
	7	1	1	3	1	
	8	0	0	1	1	
	9	1	1	0	1	
	≥ 10	0	0	1	1	
Approach Time		14	14	15	14	

that the simulated vehicles have undergone exactly the same logical process in both cases. It further implies that the numerical integration error propagated by the choice of Δt was satisfactory for 1.5 seconds, for the dynamics involved.

However, there may be significant differences in the structure of a load event, at any instant of time on a bridge deck. An analysis of the $\Delta t = 1.5$ case against the $\Delta t = 0.5$ case indicated

1. A significant difference of the total number of load events defined, i.e.,

   a. 140 events for $\Delta t = 0.5$ sec.

   b. 120 events for $\Delta t = 1.5$ sec.

This, in itself, could cause no significant affect upon the structural program, if the spatial relationships of the vehicles defining each event were preserved. This is true because the structural program disaggregates the simulator defined events into a new set of load events that are defined by the dynamic behavior of any given bridge, i.e., from steady state through the transient load state and back to steady state.

However, the observed behavior of events, see Table 15., between the $\Delta t = 0.5$ and the $\Delta t = 1.5$ cases, indicated the following behavior:

TABLE 15 - Comparison of Behavior for 1.5 Sec vs .5 Sec DELTIM

Time for 1.5 Sec Case	Exact Event	Same Event/ Minor Position Variations	Same Event/ Large Position Variations	Same Event Content/ Different Relation-ships	Differ-ent Event	Unex-plained Time Variation	Time for .5 Sec Case	Remarks
30.0		x					29.0	1 Sec Lag
54.0				x			53.0	
72.0		x					71.0	
78.0					x		77.0	
84.0			x				83.0	
96.0		x					95.0	
126.0		x					125.0	
145.5		x				x	142.5	
153.0					x		152.0	
156.0		x					155.0	
162.0		x					161.0	
181.5		x					180.5	
186.0		x					185.5	
192.0	x						191.0	
198.0		x					197.0	
204.0			x				203.0	
300.0		x					299.0	
336.0			x				335.0	
342.0		x					341.0	
373.5		x					372.5	
394.5					x		393.5	
433.5		x					432.5	
469.5					x		468.5	
522.0		x					521.0	
528.0		x					527.0	
568.5					x		567.5	
582.0	x						581.0	
588.0				x			587.0	
600.0					x		599.0	

TABLE 15 (Cont'd) - Comparison of Behavior for 1.5 Sec vs .5 Sec DELTIM

Time for 1.5 Sec Case	Exact Event	Same Event/ Minor Position Variations	Same Event/ Large Position Variations	Same Event Content/ Different Relation-ships	Differ-ent Event	Unex-plained Time Variation	Time for .5 Sec Case	Remarks
606.0			x				605.0	
612.0					x		611.0	
618.0					x		617.0	
708.0			x				707.0	
726.0		x					725.0	
738.0					x		737.0	
750.0	x						749.0	
834.0	x						833.0	
906.0	x						905.0	
960.0		x					959.0	
966.0				x			967.0	
1003.5		x					1002.5	
1008.0	x						1007.0	
1014.0					x		1013.0	
1020.0			x				1020.0	Pos Var Due to Lag
1044.0	x						1043.0	
1048.5					x		1047.5	
1074.0		x					1073.0	
1080.0	x						1079.0	
1095.0	x						1094.0	
1116.0		x					1115.0	
1122.0	x						1121.0	
1170.0				x			1169	
1213.5		x					1212.5	
1218.0		x					1217.0	
1248.0	x						1247.0	
1287.0					x		1286.0	

TABLE 15 (Cont'd) - Comparison of Behavior for 1.5 Sec vs .5 Sec DELTIM

Time for 1.5 Sec Case	Exact Event	Same Event/ Minor Position Variations	Same Event/ Large Position Variations	Same Event Content/ Different Relation-ships	Differ-ent Event	Unex-plained Time Variation	Time for .5 Sec Case	Remarks
1291.5					x		1290.5	
1302.0		x				x	1302.5	
1308.0		x					1307.5	
1338.0					x		1337.0	
1356.0		x					1355.0	
1372.0					x		1271.0	
1404.0		x					1403.0	
1416.0					x		1415.0	
1432.5		x					1431.5	
1438.5		x					1437.5	
1476.0		x					1475.0	
1482.0		x					1481.0	
1488.0		x					1487.0	
1638.0				x			1637.0	
1644.0			x				1643.5	Lag Var?
1668.0			x				1667.0	
1710.0					x		1710.0	Lag Var?
1722.0		x					1721.0	
1734.0			x				1733.0	
1764.0		x					1766.0	Lag Var?
1770.0	x						1769.0	
1786.5			x				1785.5	
1788.0			x				1787.0	
1807.5	x						1806.5	

TABLE 15 (Cont'd) - Comparison of Behavior for 1.5 Sec vs .5 Sec DELTIM

Time for 1.5 Sec Case	Exact Event	Same Event/ Minor Position Variations	Same Event/ Large Position Variations	Same Event Content/ Different Relationships	Different Event	Unexplained Time Variation	Time for .5 Sec Case	Remarks

	No.	%
Events Evaluated:	80	100.0
Column 2:	13	16.2
Column 3:	34	42.5
Column 4:	11	13.8
Column 5:	5	6.2
Column 6:	17	21.2
Column 7:	2	2.5

1. Exact duplication of an event.

2. Minor spatial variations but retaining the same event content and relationships.

3. Large spatial variations, between 10 feet and 100 feet positionally, but retaining the same event content and relationships.

4. Large spatial variations and variation in relationships but retaining the same content.

5. Some vehicles retaining same positions and relationships, but total vehicle content not the same.

6. Same or similar event, but an unexplainable time of occurrence variation.

At this point in the research, the above variations are not necessarily significant. The economies saved by using a larger Δt may be worth far more than attempting to preserve unknown or doubtful event statistics. The variations in the definitions of the events due to choice of Δt were due to the reasons discussed below.

The cause of the variation in the number of events as a function of Δt was due to the effective bridge length used by the program to define an event, i.e., if a truck would have an axle on the bridge at the next time step and a truck still had an axle on the deck in a current time step, then the event continued as the same event. The implied bridge lengths as a function of Δt were:

Δt	Max. Speed	Minimum Speed
.5	279 ft.	301 ft.
1.0	308 ft.	353 ft.
1.5	337 ft.	404 ft.
2.0	366 ft.	456 ft.

where the specified bridge length was 250 ft.

When the logical occurrences were identical a Δt of 1.5 seconds gave exactly the same positional values, at the same time, as Δt of .5 seconds.

Automobile motion appeared to be logically manipulated better at Δt = .5 than at Δt = 1.5 which also causes a variation in event structure. Typically more autos were present in the Δt = .5 samples than the Δt = 1.5 and tended to be more intermingled with the trucks than the Δt = 1.5 case. This was valid if the manner in which the passing logic operates is considered.

At maximum allowed speed, an auto could move ~117 feet for a Δt of 1.0 seconds. However, it needed to only move 60 feet to satisfy the minimum passing criteria, three logical steps were involved,

1. Move from lane 1 to lane 2

2. Pass automobile in lane 1

3. Move from lane 2 to lane 1.

In order to accomplish these three steps a minimum of two time steps were required. To pass a maximum length truck an automobile needed to only move 94 feet in one time step.

A comparison of the Δt = 2.0 seconds with the Δt = 0.5 seconds indicated the same numerical error. The incidence of agreement in event content, spatial accuracy and relationships was obviously less than for Δt = 1.5, see Table 16., 8.8% for Δt = 2.0 sec. vs. 16% for Δt = 1.5 for exact agreement. It should be noted that these figures did not represent all time points, only those points sampled. The use of a Δt = 2.0 seconds appeared to induce very serious degradation in the definition of deck load events. However, calculational accuracy of the numerical integration was retained for those events having exactly the same logical operations imposed upon them.

Again, the use of Δt = 2.0 seconds is of consequence only if valid event statistics are to be preserved.

The comparison of Δt = 1.0 sec. case with the Δt = 0.5 sec. case indicated a much higher correlation of the total number of event samples, see Table 17, than the Δt = 1.5 sec. case. The Δt = 1.5 sec. case had an incidence of 21% of the event samples varying from the Δt = .5 case, while the Δt = 1.0 sec. case had an incidence of 8.1%. The Δt = 1.0 sec. case in general provided a much better comparison to the Δt = 0.5 case than either the Δt = 1.5 or Δt = 2.0 sec. cases.

Analytically, Δt = .5 seconds ensures that passing logic will be executed properly, since it prevents an overshoot during one time step. However, unless valid statistics are provided as parameters to this program the events generated on the deck for Δt = 1.0 seconds are quite as likely as those generated at Δt = 0.5 seconds. Hence, for the sake of economy and a compromise with the complete preservation of event behavior a Δt = 1.0 second is recommended, at this time.

TABLE 16 - Comparison of Behavior for 2.0 Sec vs .5 Sec DELTIM

Time for 2.0 Sec Case	Exact Event	Same Event/ Minor Position Variations	Same Event/ Large Position Variations	Same Event Content/ Different Relation-ships	Differ-ent Event	Unex-plained Time Variation	Time for .5 Sec Case	Remarks
30.0			x				27.0	3 Sec Lag?
52.0			x			x	50.0	
74.0		x					71.0	
98.0		x					95.0	
128.0					x		126.5	Similar Event
148.0			x			x	140.5	
184.0		x					181.0	
204.0			x				201.0	
346.0					x		343.0	
376.0			x				373.0	
394.0				x			291.0	
436.0		x					433.0	
470.0					x		467.0	
524.0		x					521.0	
568.0			x				565.0	
580.0			x				577.0	
592.0		x					589.0	
686.0				x			683.0	
710.0			x				707.0	
718.0			x				715.0	
728.0		x					725.0	
750.0	x						747.0	
810.0				x			870.0	
836.0	x						833.0	
906.0			x				903.0	
962.0		x					959.0	
1004.0		x					1001.0	
1048.0		x					1045.0	

TABLE 16 (Cont'd) - Comparison of Behavior for 2.0 Sec vs .5 Sec DELTIM

Time for 2.0 Sec Case	Exact Event	Same Event/ Minor Position Variations	Same Event/ Large Position Variations	Same Event Content/ Different Relation-ships	Differ-ent Event	Unex-plained Time Variation	Time for .5 Sec Case	Remarks
1060.0				x			1057.0	
1078.0					x		1075.0	
1096.			x				1093.0	
1118.0					x		1115.0	
1156.0			x				1153.0	
1170.0	x						1167.0	
1176.0			x				1173.0	
1216.0					x		1213.0	
1248.0	x						1245.0	
1290.0				x			1287.0	
1306.0		x					1303.0	
1336.0				x			1333.0	
1354.0					x		1351.0	
1370.0					x		1367.0	
1404.0			x				1401.0	
1418.0			x				1415.0	
1436.0					x		1433.0	
1480.0		x					1477.0	
1490.0			x				1487.0	
1500.0		x					1497.0	
1640.0					x		1637.0	
1670.0			x				1667.0	
1704.0					x		1701.0	
1714.0					x		1711.0	
1726.0			x				1723.0	
1738.0			x				1735.0	
1770.0	x						1767.0	
1790.0					x		1787.0	
1802.0			x				1799.0	

TABLE 16 (Cont'd) - Comparison of Behavior for 2.0 Sec vs .5 Sec DELTIM

Time for 2.0 Sec Case	Exact Event	Same Event/ Minor Position Variations	Same Event/ Large Position Variations	Same Event Content/ Different Relation-ships	Differ-ent Event	Unex-plained Time Variation	Time for .5 Sec Case	Remarks

	No.	%
Events Evaluated	57	100.0
Column 2:	5	8.8
Column 3:	13	22.8
Column 4:	20	35.1
Column 5:	6	10.5
Column 6:	13	22.8
Column 7:	2	3.5

TABLE 17 - Comparison of Behavior for 1.0 Sec vs .5 Sec DELTIM

Time for 1.0 Sec Case	Exact Event	Same Event/ Minor Position Variations	Same Event/ Large Position Variations	Same Event Content/ Different Relation-ships	Differ-ent Event	Unex-plained Time Variation	Time for .5 Sec Case	Remarks
28.0		x					27.0	1 Sec Lag
32.0	x						31.0	
51.0			x				50.0	
54.0	x						53.0	
70.0		x					69.0	
79.0		x					78.0	
83.0					x		82.0	
87.0					x		86.0	
97.0		x					96.0	
101.0		x					100.0	
126.0			x				125.0	
128.0				x			127.0	
142.0			x				141.0	
150.0			x				149.0	
163.0			x				162.0	
181.0		x					180.0	
188.0		x					187.0	
204.0		x					203.0	
291.0			x				290.0	
300.0		x					299.0	
335.0				x			334.0	
342.0					x		341.0	
347.0			x				346.0	
373.0		x					372.0	
391.0		x					390.0	
434.0		x					433.0	
466.0			x				465.0	
523.0		x					522.0	
532.0	x						531.0	

TABLE 17 (Cont'd) - Comparison of Behavior for 1.0 Sec vs .5 Sec DELTIM

Time for 1.0 Sec Case	Exact Event	Same Event/ Minor Position Variations	Same Event/ Large Position Variations	Same Event Content/ Different Relation-ships	Differ-ent Event	Unex-plained Time Variation	Time for .5 Sec Case	Remarks
567.0			x				566.0	
576.0		x					575.0	
582.0	x						581.0	
590.0		x					589.0	
596.0		x					595.0	
604.0					x		603.0	
615.0			x				614.0	
618.0				x			617.0	
684.0			x				683.0	
708.0			x				707.0	
716.0		x					715.0	
726.0		x					725.0	
734.0					x		733.0	
748.0	x						747.0	
807.0				x			806.0	
834.0	x						833.0	
904.0		x					903.0	
960.0		x					959.0	
1001.0		x					100.0	
1011.0			x				1010.0	
1022.0		x					1021.0	
1043.0	x						1042.0	
1058.0				x			1057.0	
1072.0			x				1091.0	
1077.0					x		1076.0	
1094.0		x					1093.0	
1116.0		x					1115.0	
1154.0		x					1153.0	
1167.0	x						1166.0	
1212.0				x			1211.0	

TABLE 17 (Cont'd) - Comparison of Behavior for 1.0 Sec vs .5 Sec DELTIM

Time for 1.0 Sec Case	Exact Event	Same Event/ Minor Position Variations	Same Event/ Large Position Variations	Same Event Content/ Different Relation-ships	Differ-ent Event	Unex-plained Time Variation	Time for .5 Sec Case	Remarks
1217.0		x					1216.0	
1244.0		x					1243.0	
1286.0			x				1285.0	
1303.0			x				1302.0	
1308.0			x				1307.0	
1334.0				x			1333.0	
1352.0				x			1351.0	
1369.0			x				1368.0	
1402.0			x				1401.0	
1415.0		x					1414.0	
1433.0			x				1432.0	
1477.0	x						1476.0	
1487.0		x					1486.0	
1497.0		x					1496.0	
1636.0					x		1635.0	
1642.0		x					1641.0	
1668.0			x				1667.0	
1694.0			x				1693.0	
1702.0			x				1701.0	
1712.0		x					1711.0	
1722.0		x					1721.0	
1734.0		x					1733.0	
1764.0	x						1763.0	
1773.0		x					1772.0	
1778,0			x				1777.0	
1786.0		x					1785.0	
1800.0		x					1799.0	

TABLE 17 (Cont'd) - Comparison of Behavior for 1.0 Sec vs .5 Sec DELTIM

Time for 1.0 Sec Case	Exact Event	Same Event/ Minor Position Variations	Same Event/ Large Position Variations	Same Event Content/ Different Relation-ships	Differ-ent Event	Unex-plained Time Variation	Time for .5 Sec Case	Remarks

	No.	%
Events Evaluated:	86	100.0
Column 2:	10	11.6
Column 3:	37	43.0
Column 4:	24	27.9
Column 5:	8	9.3
Column 6:	7	8.1
Column 7:	0	0.0

If valid load event statistics are provided, via the parametric input to the program, a $\Delta t = .5$ seconds should be used.

A comparison of the three test case variations is shown in Table 18. Significant factors were

1. As the time increment increases fewer comparison event points existed

2. Existence of the exact event in position and time on the pseudo-bridge showed a non-decisive behavior.

3. The existence of the same event structure and content, with minor positional variances of a few feet, were about the same for increments of 1.0 and 1.5 seconds. However, these provided twice the similarity as does an increment of 2.0 seconds.

4. Similar event structures and content with large positional variances showed a non-decisive behavior.

5. There appears to be about a 10% existence, for all cases, of the same event content but different spatial relationships between the vehicles, i.e., leading vs. following, and lane occupancy.

6. There was clearly a decrease in the incidence of dissimilar events at the same sample time points as the time increment approaches .5 seconds.

7. There was also an apparent decrease in the occurrence of unexplainable time variations for the same or similar events, as the time increment approached .5 seconds.

TABLE 18 - Comparison of Case Variations From .5 Sec.

Test Case	No. of Events	% Exact Events	% Same Events/ Minor Var.	% Same Events/ Large Var.	% Same Event/ Diff Rel.	% Different Events	% Unexp. Time Var.
1.0 vs. .5	86	11.6	43.0	27.9	9.3	8.1	0.0
1.5 vs. .5	80	16.2	42.5	13.8	6.2	21.2	2.5
2.0 vs. .5	57	8.8	22.8	35.1	10.5	22.8	3.5

There also appeared to be a divergence trend, as simulation time increases, of event equality and similarity between the different time increment cases. The larger time increment cases diverged more rapidly than the smaller time increment cases. There was also a definite decrease in the number of unexplainable deviations in time as the DELTIM value approaches .5 seconds.

In general, the results shown in Table 18., as should be expected, indicate better correspondence with the .5 second case as the time increment approaches that value. As previously indicated, a value of 1.0 seconds is borderline and usable unless specific platoon event statistics are to be preserved. In this instance, a value of .5 seconds should be used. For the purposes of economy the larger time increments are better, obviously.

Restricted Zone Test - The testing of the restricted zone capability of the simulator was more of an analysis of its proper functioning than a sensitivity analysis. However, a sensitivity analysis was performed on the resulting data, in terms of affect upon generated truck load events. A control case having all of the same parameters, excepting restricted zones, was run to provide a basis for evaluating the effects to the generated bridge loads by various zoning options and configurations, as previously described in the test specification. Any other form of analysis would be meaningless in the context of bridge loading synthesis.

The basic parameters were as follows:

1. Md. 301 traffic distribution data.

2. A binary platoon distribution function.

3. SIMTIM = 1 hour.

4. SDFAC = 15.

5. An approach roadway of 2000 feet.

6. t = 1.0 sec.

Traffic flow was basically unidirectional for the sensitivity testing with functional testing of bidirectional flow.

The analysis of the effects was performed in the same manner as for the DELTIM testing, i.e., in terms of the similarity of the load events on the pseudo-bridge at equivalent simulation times.

The effects reflected in the unidirectional flow cases were first evaluated, in the following order:

<u>Unidirectional</u>

1. Case f (Control Case) vs. Case 2a (50 ft. restricted with no grades).

2. Case f (Control Case) vs. Case 2b (750 ft. restricted with 10% grade).

3. Case f (Control Case) vs. Case 2c (1950' restricted with -5% grade).

4. Case f (Control Case) vs. Case 2d (750' restricted with 10% grade).

5. Case f (Control Case) vs. Case 2e (1950' restricted with 5% grade).

6. Case f (Control Case) vs. Case la (5 zone hilly type approach).

Bidirectional

7. Case lb (i) (Control Case) vs. Case lb (iii) (50 ft. restricted with no grades).

8. Case lb(i) (Control Case) vs. Case lb(ii) (5 zone hilly type approach).

The analysis of Case 2a, the 50' restricted zone with unidirectional flow, adjacent to the bridge without grade indicated that variations were induced when compared to the control case. The choice of a 50' zone length was almost too short to provide a measurable variation. However, the following characteristics were observed, due to this parameter variation, in a sample of 80 events in a simulation time of 1/2 hour:

1. No change in event occurrence was observed. A one-to-one correspondence existed.

2. All events occurred at exactly the same time as for the control case.

3. Sparce vehicle events gave no evidence of variation. Variations tended to occur for dense vehicle events.

4. Exact duplication of events, and their time of occurrence, occurred in 76.25% of the events.

5. Minor positional variations were observed in 17.5% of the events. These variations were typically due to auto position variations, as opposed to truck variations.

6. Large positional variations occurred in 3.75% of the events, and were typically again observed in auto position change.

7. Only 2.5% of the events evidenced vehicle content variation. In both cases, the variation in the vehicle content was one auto.

The use of a restricted zone, without grade, as short as 50 feet will produce variations in the behavior of truck load events for a pseudo-bridge length. However, such variations, based on this test do not materially affect the vehicle content nor the timing of a load event.

It should also be noted that the control case utilized 1 minute and 29 seconds of computer time in the "go" step, while this case utilized 1 minute and 32 seconds in the go step, an increase of 3 seconds.

The analysis of case 2b, the 750' -10% down grade, test case, as described in the specification; showed absolutely no effect of the imposed down grade restricted zone for uni-directional traffic. The analysis was performed on an 80 load event sample over 1/2 hour of simulated time by comparison with the control case, 2f. The generated loads were identical in space and time to those generated by the control case. This parameter variation capability within the simulator either has no meaningful effect because of its logical definition to the form of use applied in this test case, or it has never worked. It is the opinion of the investigator that this use of the BRIGLD1 simulator had not been either utilized or debugged, previously. No additional effort was expended on this apparent problem.

It should be noted that all of the restricted zone cases required a longer approach roadway length, approximately 2000 feet, and because of this the accelerations had largely converged to zero and the speeds had largely converged to the minimum allowed speed. CAse 2b utilized exactly the same amount of computer time, in the "go"step, as did the control case, i. e., 1 minute and 29 seconds. This further reinforced the above conclusion that this variation of the restricted zone capability had no affect whatsoever on the behavior of the synthesized traffic.

The analysis of case 2c, the 1950', -5% downgrade, test case resulted, again, in determining that the generated load data was exactly the same as the control case, case 2f. No effect whatever from this parameter variation was reflected in the output for 1/2 hour of simulated time spanning 80 load events. The conclusions drawn on this case were exactly the same as those presented above on case 2b.

One interesting variation in the case was found. While the exact replica of output was generated by this case for the control case, the computer time utilized in the "go" step for this case was 1 minute and 21 seconds as compared to 1 minute and 29 seconds for the control case, a decrease of 8 seconds over the control case time.

In general , this case further reinforced the belief that the restricted zone downgrade capability is not functioning in any manner for unidirectional traffic flow, i. e., it had no meaning in the simulator.

The results of case 2d, the 750' 10% upgrade case, were heartening after the two previous test cases. When compared to the control case, the following was observed.

1. The first event for this case lagged the control case's first event by 2 seconds. This implies the existence of slower moving traffic than for the control case.

2. This case, while generating exactly the same set of vehicles as the control case, compressed the number of separate load events, as previously defined, into 135 as compared to 151 for the control case; implying a stringing affect due to slower vehicle action.

3. Significantly slower speeds for truck traffic were noted at the point the trucks entered the pseudo-bridge.

4. Longer times on the pseudo-bridge were also noted for the turck traffic, which was completely consistent with the other noted behavior.

5. The structure and content of the generated load events on the pseudo-bridge were radically changed, almost totally, from those generated by the control case.

6. A few instantaneous points, especially at the commencement of a load event, were found where the load event was exactly the same as for the control case.

7. The same strong tendency for the accelerations to converge to zero and the speeds to converge to the minimum

allowed speed was noted. However, velocities and accelerations, where different from the minimum speed and non-zero respectively, were almost totally different from those output by the control case. Convergence occurred more rapidly than for the control case due to the grade slowing effect.

In general, conclusions drawn from this test indicated that the upgrade effect, at least for a significant distance, did significantly alter the generated truck load events from a non-grade form. Further, the simulation did appear to reflect the physics and dynamics expected from the imposition of a significant grade in the approach to a bridge. However, no indication of the restricted portion of the restricted zone capability could be determined separate from the effects of the upgrade. This could have been due to the fact that the effects of both variations should cause similar effects in the behavior of the traffic. However, it is the opinion of the investigators that the restricted operation did not function and that all of the effects observed for this case were due to the upgrade variation. This opinion was based primarily upon the results from the two previous test cases.

For the same period of simulation time, this case utilized 1 minute and 27 seconds of computer time in the "go" step as compared to 1 minute and 29 seconds for the control case.

The results of case 2e, the 1950' 5% upgrade case, were very similar to those of the previous case, case 2d, in behavior. In general, all of the observed effects from the previous case held for this case. Although, each event was essentially different from the previous case. Some specific results were:

1. The first event for this case lagged the control case's first event by 3 seconds. This implies slower moving traffic behavior than the control case.

2. Again, the load events were largely of different structure than the control case and the previous case. Truck behavior was significantly different than the previous case. In some instances, the same truck in this case lagged in the previous case. It was also true that this case lagged the previous case time-wise for some trucks.

3. This case compressed the total number of load events to 132 as compared to 131 for the previous case and 151 for the control case. In general, this implied an overall slightly faster traffic behavior than the previous case, which was consistent with the slopes of the grades imposed.

4. The dynamics of the vehicles forming the load events while on the pseudo-bridge were much different than for either the control case or the previous case.

The overall behavior of this case as compared to the control case was consistent with the anticipated behavior expected from the physics of the problem. Again, no measurable effect due to the restricted operation could be discerned from the effects due to the grade. The same conclusions were drawn with respect to this case as for the previous case.

Comparing a sampling of identical trucks between this case and the previous case indicated an arrival time on the pseudo-bridge for this case of approximately 3 seconds before the previous case, for the same trucks. In a very few cases, the arrival time was behind the previous case, approximately 10% of the sample. The speeds of the identical trucks on arrival at the pseudo-bridge tended to be slower or the same, in equal proportions, for this case when compared to the previous case. In a small portion of the sample, identical trucks arrived at the bridge with faster speeds than in the previous case. These results appeared to be consistent with the relative physics of the two cases, i.e., this case had a grade that was 2.6 times the length of the grade in the previous case although with only 50% of the grade.

In analyzing these two cases, another deficiency in the simulator became obvious. Truck power is limited to a single fixed, input, weight to horsepower ratio for each truck type. No provision was made for weight variations. A more realistic approach would be to input a nominal horsepower value for each type and calculate the ratio as a function of the truck's load. As it is, a fully loaded truck of a given type has the same weight to power ratio, i.e., the same acceleration potential, as an empty truck of the same type. This poses a serious question about utilizing the load data generated by the BRIGLD1 simulator for structural analysis purposes. Work at Le High has related velocity-weight relationships with bridge structural response. The simulator not only does not preserve such relationships, but falsely relates the two variables to a probable 50% of the trucks generated.

In analyzing case 1a, the hilly-like approach to the pseudo-bridge, in comparison with case 2f, the unidirectional control case, significant variation in the structure of load events and the dynamics were observed. However, the effects were much less in magnitude than for the simple grade cases 2d and 2e.

Observed effects were as follows:

1. The first event occurred at exactly the same time as for the control case, but was different in structure.

2. The total number of load events was compressed to 145 events as compared to 151 for the control case, and 131 and 132 for cases 2d and 2e respectively. This further substantiated the conclusion that the hilly-like variation provided effects in lesser magnitude than the simpler upgrade cases.

3. Truck behavior and ordering was exact in many instances, with a definitely measurable variation in a significant portion of the truck population.

4. Event vehicle content variation was largely due to auto variations.

5. Definite lag effects were observed which are consistent with other observed effects from this case.

6. The initiation of many events were the same or nearly the same in most cases. Variations initially or subsequently were usually due to change in auto content.

The overall observed effects were qualitatively what should be anticipated in terms of comparison with the control case. They were also consistent with the two simple upgrade cases. While the grades imposed were severe, their duration was extremely short, with a total upgrade length of only 500 feet. Again, no direct conclusions can be drawn about the restricted operation for the same reasons as previously discussed. Similarly, the downgrade effect cannot be evlauated, but it is assumed to be non-existent based upon the two simple downgrade tests.

The results of case 9b(iii) for bidirectional traffic flow with a restricted 50 ft. zone at one approach to the pseudo-bridge indicates very little variation from the control bidirectional flow case, case lb(i). On the order of ten variations were observed over a 1400 second simulation time period.

Both cases timed out on the computer at 5 minutes of execution. The control case utilized 4 minutes and 40 seconds of computer time in the "go" step for 1672 seconds of simulated time, while this case used exactly the same time, but for only 1401 seconds of simulation time.

Variations were in terms of auto positions at the same sample time. Truck behavior was exactly the same as for the control case. No change in the number of events over the same simulation period occurred.

The zone restriction operator appeared to function for bidirectional traffic flow, as opposed to the unidirectional case.

Additionally, initialization of truck velocities, in the 2nd direction, by the simulator's generator evidenced a tendency to initialize improper velocities.

The results of the 5 restricted zones bidirectional test case, case 1b(ii), when compared to the bidirectional control case, case 1b(i), indicated minor but definite variations from the control case. This case represents a hilly section of road adjacent to one end of the pseudo-bridge. Ordering of truck load events appear consistent with the control case. Observed variations were in terms of change of position at the same simulation times.

A total of 1401 seconds of simulation time was synthesized in a total of 4 minutes and 40 seconds of computer time in the "go" step. This compared very closely to the previously described case, case 1b(iii). It condensed the total number of cases to 53 as compared to 54 for the control case.

A total of 22 events varied from the control case. Most variations were due to positional differences for autos. In a few cases, a change in the number of autos contained in an event occurred and in a few others, five, truck positions changed.

This case evidenced the same form of variation, slight but definite, to its control case, as did the similar unidirectional case. In this instance, the restricted zoning largely only affected 50% of the generated vehicles.

Its relative effects appeared to relate to the physics of the case.

Bidirectional traffic flow simulation increased computer CP time by a factor of 7 over unidirectional flow simulation, using 5 stipulated zones for both cases, i.e., exactly the same.

Bidirectional traffic flow with 5 zones ran at an increase of .03 CP seconds per second of CP time for a no zone bidirectional case. This implied that the bidirectional simulation is a very costly process.

A comparison of 1 zone stipulated to 5 makes no significant change in running time (CP time).

In addition to the excessive computer utilization incurred by this option, and the incorrect velocity generation of trucks in the 2nd direction, there is a serious question about the validity of the generated density for a two directional highway. It is essential that a nominal one lane traffic load be defined for a bidirectional highway because the simulator apparently doubles the given vehicle density.

Use of this option is not recommended unless significant improvement on the two way synthesis is performed. Further, the excessive computer costs make its use questionable for the purpose it is supposed to serve, i.e., long term load prediction.

Conclusions drawn on the use of the restricted zone options are summarized as follows:

1. Restricted flow of unidirectional flow did not appear to have any meaning in the simulator and only qualified effect for bidirectional flow.

2. Downgrade definitions did not appear to have any meaning in the simulator.

3. Upgrade definitions appeared to operate properly.

4. As a result of analyzing these test cases, test results indicate that the bidirectional flow simulation is questionable and certainly used a large amount of computer time, as compared to unidirectional flow.

5. Weight-velocity relationships were not adequately preserved.

SDFAC Testing - This variable controls the value utilized for safe following distance during a simulation. A value of 15, as indicated earlier is approximately the rule of thumb of one car length per each ten miles of speed, e.g., at 60 mph it establishes 117 feet as a safe following distance.

In evaluating these test cases, the SDFAC=15 case was utilized as a control case. In all cases, a simulation time of one hour was utilized, with detailed loading output at each time point within each event. The use of one hour was based upon the pragmatics of analyzing a large quantity of output and the actual printing of output. One hour of simulation generated approximately 1800 vehicles for the traffic distributions utilized. The control case generated 131 separate load events for this period of simulation.

The other important parameters utilized were:

1. An approach length of 1000 feet

2. A bridge length of 250 feet

3. Unidirectional traffic flow

4. $\Delta t = 1.0$ sec.

In performing these tests, it was noted that the use of the vehicle length speed equation to establish safe following distances may not be realistic in the case of trucks. In fact, if this program is actually utilized to generate bridge truck loadings, two equations should be established with different parameters, i.e., one for trucks and one for autos.

The results of the test case for SDFAC=5 compared to the control case, SDFAC=15, clearly indicated measurable effects occur in the generated truck load events on the pseudo-bridge when this parameter was varied. Directly, a change from 15 to 5 for a speed of 60 mph changes the safe following distance from 117 feet to 352 feet. This change implies one or both of two occurrances,

1. Lighter vehicle density is imposed, and/or

2. Slower event dynamics.

This case, because of its tendency to widely separate vehicles, increased the number of load events generated to 132. This was to be expected.

Observations of the effects of using SDFAC=5 as opposed to SDFAC=15 include:

1. Truck behavior was mostly either exactly the same or relatively minor position changes occurred at the same points of time.

2. Auto content in an event varied considerably from varying in number and position to being exactly the same.

3. Relative positional relationships were not preserved.

4. Ordering of vehicles was not preserved, including occasional shifts in truck ordering.

5. An initial lag of one second occurred for this test case, but was not consistently maintained due to the creation of a new event. The lag was restored subsequent to the new event, i.e., over the control case.

6. The first time point in each event was usually the same in both cases in terms of the truck present and its position, i.e., considering the imposed lag. Total structure of the event initially varied because of auto behavior.

7. While the initial time point might provide duplication, in some instances, invariably a later time point in the event would evidence variation of the pseudo-bridge load in terms of position and/or content.

Decreasing the SDFAC value created a restructuring of load events due to changing the safe following distance. This may impose changes in traffic dynamics which were not straightforwardly and easily predictable.

The results of the test case for SDFAC=10 compared to the control case, SDFAC=15, were very similar as those for SDFAC=5. The observed effects were pronounced and were of the same nature as the previous case. This value of

SDFAC establishes a safe following distance at 60 mph, for an auto of 234 feet when compared to the control case. The same number of generated load events were generated, 131. However, the time structure and content were not the same.

Compared to the two previous cases, the bridge load data tended to be more like the control case than the SDFAC=5 case. More events were identical in time and space to the control case than the previous case. Vehicles tended to be more frequently in the same position, at a given time, as that shown in the control case, than the previous case.

The observations were completely consistent with increasing the following distance between vehicles.

The results of the SDFAC=20 case, compared to the control case also clearly evidenced variations in load event number, vehicle content and structure. This value of SDFAC produced a safe following distance of 88 feet at 60 mph for an auto.

The sample of output analyzed indicated the following:

1. Repetition of exactly the same load event as the control case appeared in about 25% of the events. This case, on the basis of repetition of exactly the same event, was less similar to the control case than for the SDFAC=10 case.

2. Auto variations in position were more frequent than truck variations. However, truck variations were plentifully present.

3. Event structure usually varied to the inclusion of an auto in the event for this case which was not present in the same event of the control case.

This case generated 133 events as compared to 131 for the control case and was contrary to the expected and generally indicated decrease in the number of events with an increase in the magnitude of SDFAC.

The test results for SDFAC=25, as compared to the control case, and the SDFAC-20 case were evaluated over a sample of the runs generated. Unlike previous cases, it was felt that this case should be compared to the SDFAC=20 case as well as the control case. This was based upon the fact that the change in the safe following distance was very small as compared to the earlier cases, e.g., see Table 19.

As anticipated, of the sample analyzed 28.6% of the time points were exactly the same for the SDFAC=20 case and this case. This compares to 11.9% of the time points sampled being exactly the same as the control case. Further, another 28.6% of the time points were very similar between this case and the SDFAC=20 case. The same comparison between the control case and this case revealed only 14.3% of the time points being very similar. The remainder of the sample points varied mostly due to changes in auto position in the event or the auto content. A few had significant truck position variation and content.

The variations noted for this case were of the same form observed previously for the other cases in this set. The small variation in the safe following distance between this case and the SDFAC=20 case, e.g., 18 feet at 60 mph for autos, still caused significant variations in the descriptions generated of the load events.

TABLE 19 - Auto Safe Distance Value (60 mph) vs. SDFAC

SDFAC	Auto Safe Following Distance (60 mph)
5	352 Feet
10	176 Feet
15	117.3 Feet
20	88 Feet
25	70.4 Feet

As the following distance is allowed to decrease there should be a tendency to have more vehicles in an event. Thus, a reduction in the total number of events should be anticipated. As can be seen in Table 20., there appears to be an overall weak tendency to decrease the total number of events as SDFAC increases. This is due to shortening of the safe following distance and a consequential reduction of the distances between trucks. This then has the tendency to string platoons into larger platoons, in terms of the definition utilized in the program.

The simulation of vehicle dynamics by the BRIGLD1 simulator is extremely sensitive to variations in the value of SDFAC. Consequently, load events are similarly sensitive to changes in this value. At equal incremental values of SDFAC the change in the safe following distance increases significantly as the value of SDFAC decreases, i.e., it varies as the reciprocal of SDFAC. Larger values of SDFAC will cause proportionately smaller changes in the safe following distance.

It is felt that as indicated earlier, a better representation of safe following distance is needed in the simulator, as opposed to the one simple equation presently used. The choice of this value materially affects the vehicle dynamics and acts as a constraint on the vehicle statistics. The mathematical model of the safe following distance should not only consider vehicle differences, but also traffic behavior differences as a function of a given highway.

Extreme care must be used in the variation of this parameter. Studies of bridge loading effects on a given highway should consistently utilize the same value, and it should relate to the traffic behavior of that highway.

TABLE 20 - Platoon Distribution of Bridge Captured Loads

PLATOON COUNT

SDFAC \ Platoon Size	1	2	3	4	5	6	7	8	9	10	Tot.
5	62	28	15	10	9	4	2	0	0	1	131
10	61	29	12	10	11	4	2	0	0	1	130
15	61	23	17	13	9	5	1	0	1	0	130
20	63	24	16	14	8	5	1	0	1	0	132
25	60	25	15	13	8	3	0	1	0	129	
Percentage Incidence											
5	47.3	21.4	11.4	7.6	6.9	3.0	0	0	0	0.8	100
10	46.9	22.3	9.2	7.7	8.5	3.1	0	0	0	0.8	100
15	46.9	17.7	13.1	10.0	6.9	3.8	0.8	0	0.8	0.0	100
20	47.7	18.2	12.1	10.6	6.1	3.8	0.8	0	0.8	0.0	100
25	46.5	19.4	11.6	10.1	6.2	3.1	2.3	0	0.8	0.0	100

DEVELOPMENT OF THE DYNAMIC STRESS PROGRAM

This section of the report presents the basis of the dynamic structural analysis program which was developed to utilize the generated load data from the BRIGLD1 Simulator and to, in turn, predict the stress caused by the synthetic loads in a given bridge design. The ultimate purpose of the joint use of these two programs, as indicated earlier, is to provide a basis for the prediction of long term fatigue.

The generated load data are assumed to form a force vector which varies with time, $[F(t)]$, and is the driving function in the nonhomogeneous differential equation.

$$[F(t)] = [K][\delta] + [m\ddot{\delta}].$$

where $[K]$ is the unit stiffness matrix for an "effective" beam,

$[\delta]$ is the displacement vector,

m is the element mass which is accelerating

and $\ddot{\delta}$ is the element acceleration.

As is implied in the foregoing, the bridge is subdivided into a rectangular grid system, elements. The longitudinal center line of each rectangular grid is the center line of a main girder. The longitudinal width of each grid is nominally 10 feet. The time dependent load, $[F(t)]$, is applied to the geometric center of each grid element.

Two forms of basic bridge structures were assumed:

1. A simple span bridge, and
2. A continuous span bridge.

The simple span bridge is evaluated on the basis of the deflections of the effective longitudinal beams when subjected to bending. The continuous span bridge is identically calculated, except that each supported section of the span is assumed to be a free body. This imposes the need to determine the discontinuity moments at each support position and reintroducing these discontinuity moments in the simple span stress calculations. This re-establishes necessary continuity.

The solution to the discontinuity moments and shears at the intermediate supports are calculated via the "3 moments equations" for the bending fiber stresses. The strength of material approach utilized herein for the beam element stiffness matrix provides the user/engineer a means to achieve better understanding of the stress fatigue problem. The direct stiffness method developed for the analysis of assembling the plate and rib stiffness is certainly comparable to the beam element stiffness process in which the anisotropic composition of deck plate and beam rib is taken care of as the effective modulus of the bending rigidity. The correct stiffness for the representation of the bridge is only relatively important so long as the load distribution causes the proper results in deflection values.

Structural Analysis

The study of truck loadings on a bridge deck has been investigated by many authors, besides the general guideline presented by AASHO methods, The objective of this approach is to provide a basic flexural beam-element analysis method, suitable for a computerized analysis of a bridge design, undergoing dynamic loading. The complete treatment of the finite element method of an orthotropic slab-beam in the

principal directions was not the intent of this project. It was more convenient to formulate an orthogonal beam element (grid network) on the bridge deck, so as to distribute the loading in a reasonable fashion. It was pointed out by Scordelis, et al, that the empirical formula $N_{WL} = \frac{S}{7}$ wheel load for interior girders may not be accurate for design use. Thus some other assumptions were made and are described herein, for the analysis of loadings on the girders. The exterior girders are designated to carry a fraction of wheel loads $N_{WL} = S_i/7$, (S_i is equal to the half-flange width plus the overhang flange in feet).

A complete treatment to the force displacement via the finite element method was much too cumbersome to achieve the basic objectives within project constraints. A more rational approach was selected for the computing of the deck stiffness in the transverse direction by considering the beam-plate in the transverse direction to be simple supported at both ends which is generally considered to be rigid with the girder and overhang flange. In accordance with the Timoshenko and Wainowsky-Krieger, the plate is assumed cross stiffened by two sets of equidistant stiffeners. The bridge can then be assessed for bending behavior by calculating the longitudinal and transverse plate stiffnesses separately for the effective modulus. The determination of the effective modulus for the bending stress calculation is shown later in the report. If the computerized program is to be developed for the solution of the detailed stress distribution in the vicinity of a wheel load, then, a finer grid will be needed and it will be necessary to utilize the anisotropic slab stiffness of D_x, D_y and D_{xy} to account for applied loading distribution. However, a modular anisotropic routine can be added for this particular interpretation for the determination of the stress distribution, in the composite section of concrete slab and

girder, as well as the bents or diaphragm. This portion of the report will be restricted to considering the main deck stress

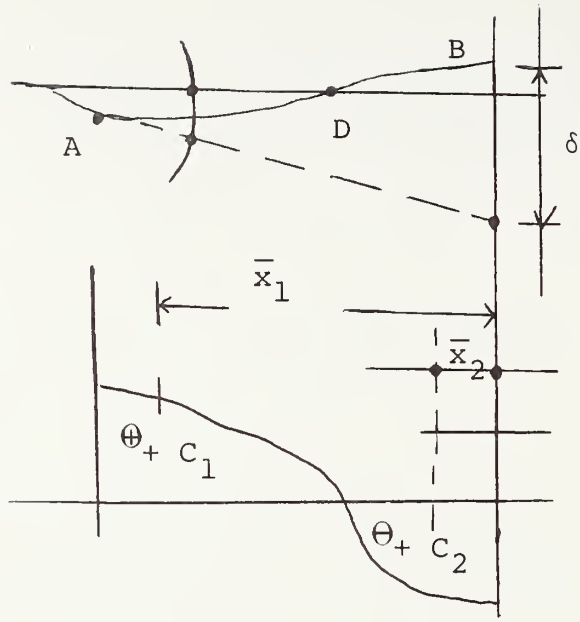
The variation of the EI along the beam must be taken into account. The local average of the beam-slab combination is used in the calculations as will be discussed later in this report, for example,

If $X_i = X_j$, then

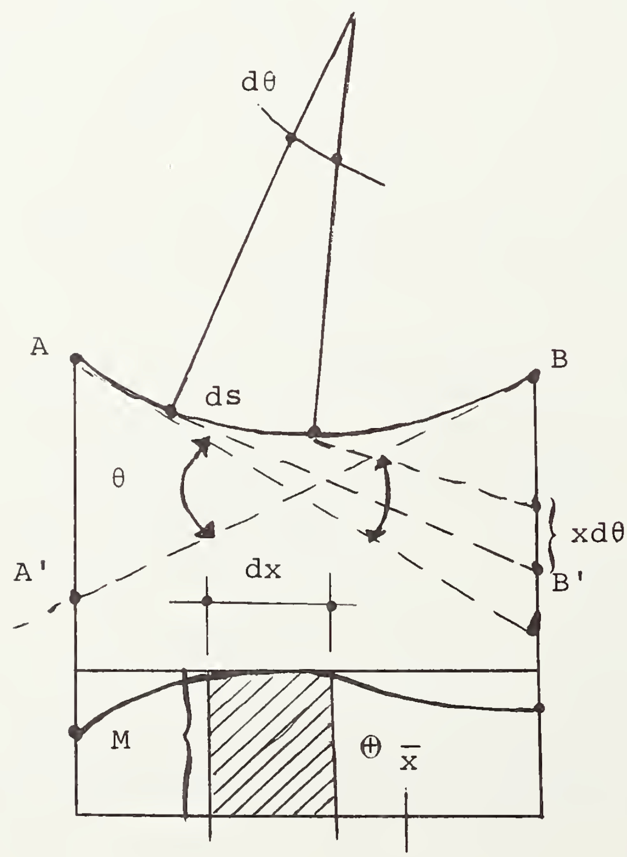
$$\delta_{ii} = \delta_{jj} = \frac{\ell}{k_{ii}} = \frac{X_i(\ell - X_i)}{6\ell\ EI} [\ \ell^2 - X_i^2 - (\ell - X_i)^2]$$

It should be noted that this forms the principal diagonal in the assembled stiffness matrix for the bridge deck, which consists of multiple beam elements on a bridge deck. The lateral beams on the bridge are defined as the deck plate with intermittent synthetic beams, diaphragms, connected between the main beams. These synthetic beams or stiffners account for the beam stiffness in the lateral direction, much the same way as the longitudinal effective beams. These synthetic stiffners are assumed supported at the edges of a deck. The numerical stiffness is computed by using the same equation as above, when the lateral plate and the intermittent rib stiffnesses are considered as the effective cross-section of the beam.

The continuous span was considered in different manner for the stiffness matrix formulation. The influence coefficients can be evaluated by considering the bending moment area for the main girder-deck system. The discontinuity moment at the support juncture is considered to be contributory to the deflection of the beams and can be determined by the integral of the area under moment diagram M/EI. Then, the deflection between grid points can be represented by the bending moment area integral with respect to any grid point under unit loading at the beam on the grid point.



B
A
D
δ
$\bar{x}_1$
$\bar{x}_2$
$\Theta_+ C_1$
$\Theta_+ C_2$



dθ
A
B
ds
θ
xdθ
A'
dx
B'
M
$\Theta\ \bar{x}$

$$\delta_{AB} = \frac{D}{A}\left(\frac{Mxdx}{EI}\right) - \frac{B}{D}\left(\frac{Mxdx}{EI}\right)$$

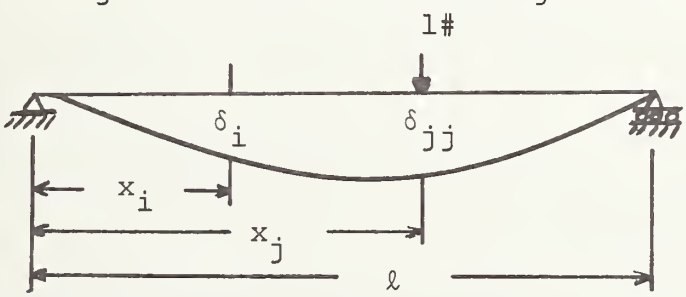
$$= \frac{\text{Moment Area}}{EI}\left(\frac{D}{A}\right)\bar{x}_1 \quad \frac{\text{Moment Area}}{EI}\left(\frac{B}{D}\right)\bar{x}_2$$

Simple Support Span and Continuous Span

Considering a linear system of beam rib elements along the longitudinal direction simply supported at ends, the influence coefficients of a simply supported beam will be defined as δ_{ij}, i.e., the deflection of the beam at node i due to a unit force at node j. δ_{ii} will be the deflection at i due to a unit load at i. The simple supported beam can then be subdivided into the various grid points, both in the longitudinal and transverse directions. For the longitudinal beam, $\delta_{ii} = \frac{1}{k_{ii}}$ at node x_i is written as:

$$\delta_{ii} = \frac{1}{k_{ii}} = \frac{x_i\ (\ell - x_i)}{6\ell\ EI}\ \{\ \ell^2 - x_i^2 - (\ell - x_i)^2\}$$

For the deflection of any node i, due to an axle load located at node j where j is situated on the right side of the node



can be written as

$$\delta_{ij} = \frac{1}{k_{ij}} = \frac{x_i\ (\ell - x_j)}{6\ \ell\ EI}\ \{\ \ell^2 - x_i^2 - (\ \ell - x_j)^2\}$$

This represents the deflection of any node i to the left of the axle load j on the beam. In evaluating this deflection

for any node along the beam, it is important to note that the EI are the composite beam stiffness (plate and rib), in the longitudinal direction. $\delta_{A/B}$ is the deflection due to a unit load at point A with respect to point B at any grid point between the beam, say δ_{ij}. Then, the inverse of the influence coefficient matrix will be the stiffness matrix. δ_{ij} is the influence coefficient of the grid system and

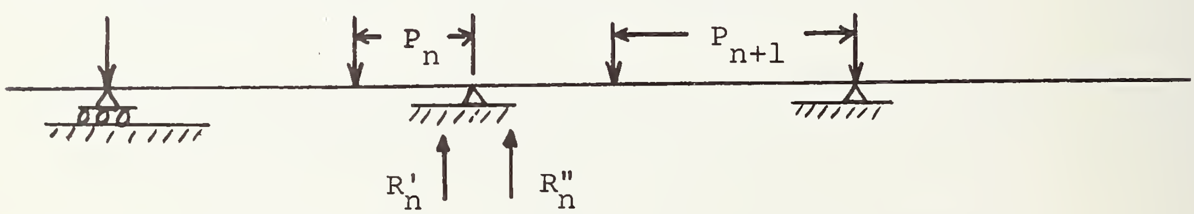
$$[K] = [\delta]^{-1}$$

Once the moment diagram on each span of the beam is calculated, then, the reaction force may be produced in a similar way using the discontinuity bending moment method; i.e.,

$$R_n = R'_n + R''_n + \frac{M_{n-1} - M_n}{\ell_n} - \frac{M_n + M_{n+1}}{\ell_{n+1}}$$

R'_n = Reaction force due to load on span n

R''_n = Reaction force due to load on span n + 1



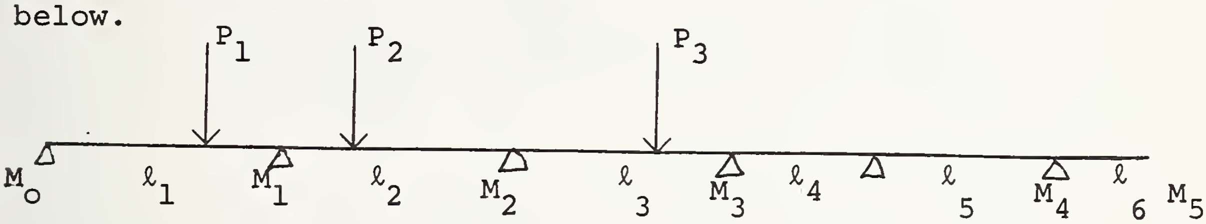
Where $$R'_n = \frac{P_n b_n}{\ell_n}$$

$$R''_n = \frac{P_{n+1} A_{n+1}}{\ell_n}$$

$$R_n = \frac{P_n b_n}{\ell_n} + \frac{P_{n+1} A_{n+1}}{\ell_{n+1}} + \frac{M_{n-1} - M_n}{\ell_n} + \frac{-M_n + M_{n+1}}{\ell_{n+1}}$$

$$= \frac{P_n b_n + M_{n-1} - M_n}{\ell_n} + \frac{P_{n+1} A_{n+1} - M_n + M_{n+1}}{\ell_{n+1}}$$

For a continuous span, the loading on bridge deck can be utilized to calculate the moment on the main girder, or beam. The total summarized moments can be computed with the procedure outlined below.



1. Calculate, M_1, M_2, M_3 based on the discontinuity moment matrix from loads P_1, P_2, and P_3 independently on each span. Then, sum up the moments M_{P1}, M_{P2}, and M_{P3} from the loads P_1, P_2, and P_3 on the various spans. The total discontinuity moment at any given time t_1, on support 1 will be equal to

$$M_{D_1}^{(t_1)} = (M_{P1} + M_{P2} + M_{P3} + M_{pn})$$

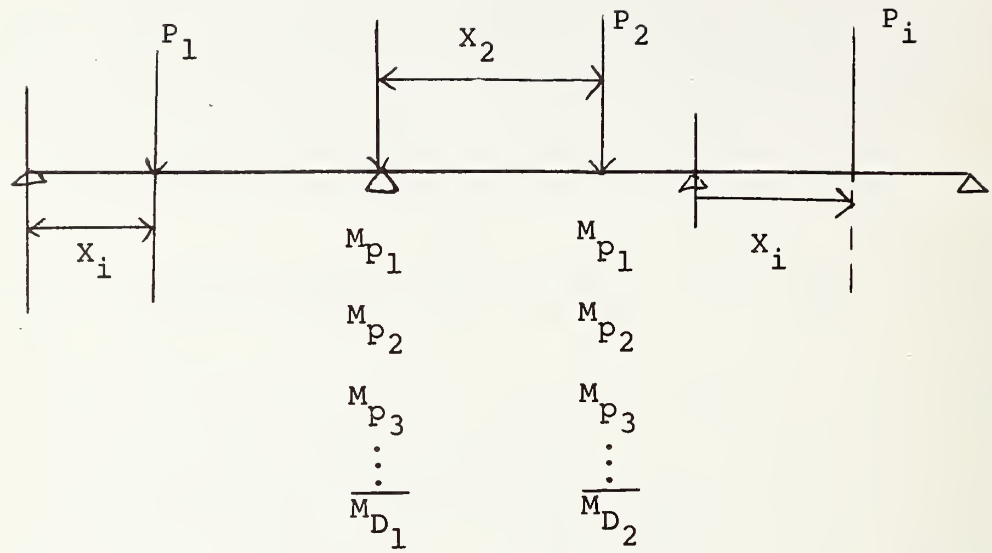
$$= \sum_{P=1}^{P=P_n} M_{Pn} (t_1)$$

$$M_{P2}(t_1) = \Sigma (M_{P1} + M_{P2} + M_{P3} + M_{P4})$$

If more than one load exists on any span, the moment calculation remains the same as above, and is essentially additive.

2. The moment due to any load P_i distribution on any span ℓ_n will be computed as if the span is simply supported.

$$M_{0-1} = \text{Moment due to load } P_i \text{ in span } 0 - \ell = \frac{P_i X_1 (\ell_1 - X_i)}{\ell_1}$$



P_1
X_2
P_2
P_i
X_i
M_{p_1}
M_{p_2}
M_{p_3}
M_{D_1}
M_{p_1}
M_{p_2}
M_{p_3}
M_{D_2}
X_i

$$\therefore \quad M_n = \frac{P_i X_i (\ell_n - X_i)}{\ell_n}, \text{ and}$$

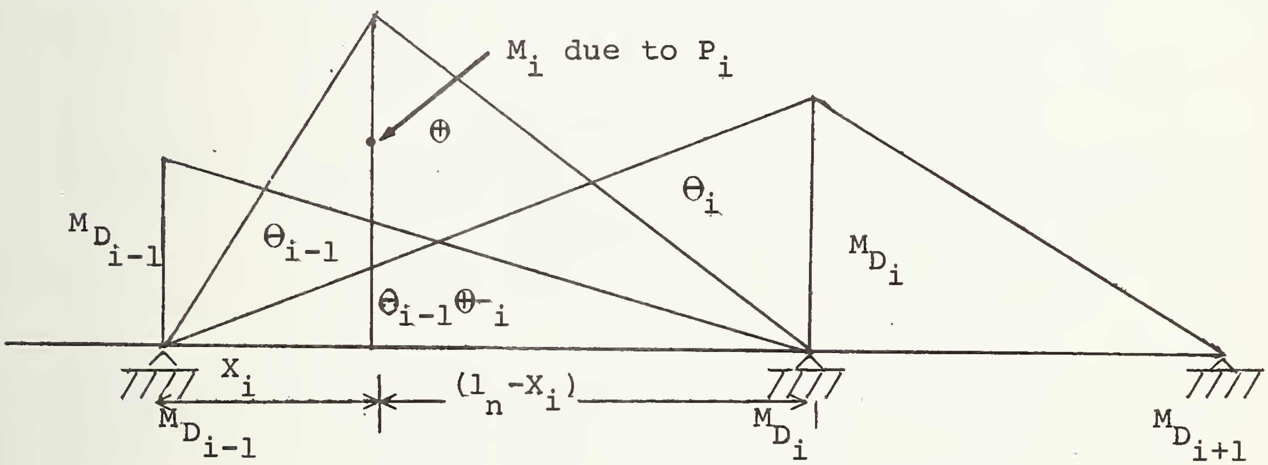
is the moment due to load P_i of the n^{th} span. If more than one load exists on span n, then

$$M = \sum_{i=1}^{n} \frac{P_i X_i (\ell_n - X_i)}{\ell_n}$$

3. The total moment distribution, on span ℓn, including the discontinuity moment, is determined from

$$\overline{M} = \sum_{i=1}^{n} \frac{P_i X_i (\ell_n - X_i)}{\ell} \pm M_{D_n} \frac{(\ell_n - X_i)}{\ell_n} \pm M_{D_{n-1}} \frac{(\ell_{n-1} - X_{i-1})}{\ell_{n-1}}$$

For example:



In general, the discontinuity moment M_{D_i} is negative in value, except the complicated case when there is more than one load acting, for example, loads acting on an adjacent span which may cause an inflection in the curvature of span i.

4. Bending stress

$$\sigma_B \text{ (Stress) on steel girder} = \frac{\overline{M}_i}{Z_i} = \frac{\overline{M}_i}{\dfrac{EI_{si}}{E_s C_2}}$$

$$\sigma_B \text{ (concrete girder)} = \overline{M}_i / \frac{EI_{ci}}{E_c C_2}$$

Each end on the continuous span is assumed to be simply supported. If it is a built-in end, one more equation expressing the condition that no end rotation will take place at the support. The angular rotation vanishes at the built-in end.

$$n = 0$$

$$\Theta_o = 0 = \text{angular slope at built-in end}$$

Left Span,

$$\theta_n' = \frac{M_n \ell_n}{3EI_n} + \frac{M_{n-1} \ell_n}{6EI_n} + \frac{A_n C_n}{n\, EI_o}$$

Right Span,

$$\Theta_n'' = \frac{M_n \ell_{n+1}}{3EI_{n+1}} + \frac{M_{n+1} \ell_{n+1}}{6EI_{n+1}} + \frac{A_{n+1} d_{n+1}}{\ell_{n+1}\, EI_{n+1}}$$

To compute the total bending moment, the moments due to each load must first be computed for the span, that is,

$M_1(x)$ = moment due to axle load 1,

$M_2(x)$ = moment due to axle load 2,

$M_3(x)$ = moment due to axle load 3,

ΣM_B = total bending moment

$= M_1(x)+M_2(x)+M_3(x)$

Where, $M_1(x) = \dfrac{P_1 a_1 b_1 x}{a_1 \ell_1} \approx \dfrac{P_1 b_1 x}{\ell_1}$, for $x_1 < a_1$

or $\dfrac{P_1 a_1 b_1 x}{\ell_1 b_1}$ for $a_1 < x < (a_1+b_1) \approx \dfrac{P_1 a_1 x}{\ell_i}$

$M_2(x) = \dfrac{P_2 a_2 b_2 x}{\ell_1 a_2} = \dfrac{P_2 b_2 x}{\ell_1}$ for $x < a_2$

or $\dfrac{P_2 a_2 x}{\ell_2}$ for $a_2 < x < l_1$

$\vec{M}_1(x_1) + \vec{M}_2(x_2)$

$= \left[\dfrac{P_1 b_i}{\ell_1} x + \dfrac{P_2 b_2 x}{\ell_1}\right]$ (valid up to axle load P_1)

or $\dfrac{P_1 a_1}{\ell_1} x + \dfrac{P_2 b_2 x}{\ell_1}$ (valid for $a_1 < x < a_2$)

or $\dfrac{P_1 a_1}{\ell_1} x + \dfrac{P_2 a_2}{\ell_1} x$ (valid for $a_2 < x$)

$\approx \left(\dfrac{P_1 b_1}{\ell_1} + \dfrac{P_2 b_2}{\ell_1}\right) x \approx \dfrac{P_1 b_1 + P_2 b_2}{\ell_1} x$, for $x < a_1$

or $\left(\dfrac{P_1 a_1 + P_2 b_2}{\ell_1}\right) x,$ for $a_1 < x < a_2$

or $\left(\dfrac{P_1 a_1 + P_2 a_2}{\ell_1}\right) x,$ for $a_2 < x$

To determine the centroid, C_n, of the bending moment diagram,

$$C_n = \frac{\Sigma \text{ Area of Moment diagram x centroid distance to point "0"}}{\text{Total area of moment diagram}}$$

To compute A_n = Area of moment diagram, due to loads on span n,

$$A_n = \frac{1}{2}\sum_{i=1}^{n} M_i L$$

5. To compute the discontinuity moments M_n, M_{n-1}, on span n.

at n = -1, $M_o = 0$ for the simple supported case, and for the built-in end at support "0", an additional equation is required:

$$\theta_0 = 0,$$

$$\therefore 0 = \theta_0 = \frac{M_0 \ell_1}{3EI_1} + \frac{M_1 \ell_1}{6EI_1} + \frac{A_1 b_1}{\ell_1 EI_1}$$

$$\text{Calculate:} \quad M_0 = \frac{-M_1}{2} - \frac{3A_1 b_1}{2\ell_1}$$

where A_1, b_1, ℓ_1, are known from previous calculations.

The end force or reaction is, then

$$R_n = R_n' + R_n'' + \frac{M_{n-1} - M_n}{\ell_1} + \frac{-M_n + M_{n+1}}{\ell_{n+1}}$$

For a simple supported continuous span, the discontinuity moments at the supports can be represented as

$$\theta_n' = \frac{M_n \ell_n}{3EI_n} + \frac{M_{n-1} \ell_n}{6EI_n} + \frac{A_n a_n}{\ell_n EI_n}$$

$$\theta_n'' = \frac{M_n \ell_{n+1}}{3EI_{n+1}} + \frac{M_{n+1} \ell_{n+1}}{6EI_{n+1}} + \frac{A_{n+1} b_{n+1}}{\ell_{n+1} EI_{n+1}}$$

$$\theta_n' = -\theta_n''$$

or,

$$M_{n-1}\left(\frac{\ell_n}{I_{n-1}}\right) + 2M_n\left(\frac{\ell_n}{I_n} + \frac{\ell_{n+1}}{I_{n+1}}\right)$$

$$+ M_{n+1}\frac{\ell_{n+1}}{I_{n+1}} = -\frac{6A_nA_n}{\ell_nI_n} - \frac{6A_{n+1}b_{n+1}}{\ell_{n+1}I_{n+1}}$$

$$\left\{\ell_n,\ 2(\ell_n+\ell_{n+1}),\ \ell_{n+1}\right\}\begin{Bmatrix} M_{n-1} \\ M_n \\ M_{n+1} \end{Bmatrix}$$

$$= -\begin{bmatrix} \dfrac{6A_na_n}{\ell_nI_n} \\ \dfrac{6A_{n+1}b_{n+1}}{\ell_{n+1}I_{n+1}} \end{bmatrix}$$

For the n = 4 span case,

$$n = 1,\ \frac{M_o\ell_1}{I_1} + 2M_1\left(\frac{\ell_1}{I_1}+\frac{\ell_2}{I_2}\right) + \frac{M_2\ell_2}{I_2} = -\frac{6A_1a_1}{\ell_1I_1} - \frac{6A_2b_2}{\ell_2I_2}$$

$$n = 2,\ \frac{M_1\ell_2}{I_2} + 2M_2\left(\frac{\ell_2}{I_2}+\frac{\ell_3}{I_3}\right) + \frac{M_3\ell_3}{I_3} = -\frac{6A_2a_2}{I_2\ell_2} - \frac{6A_3b_3}{I_3I_3}$$

$$n = 3,\ \frac{M_2\ell_3}{I_2} + 2M_3\left(\frac{\ell_3}{I_3}+\frac{\ell_4}{I_4}\right) + \frac{M_4\ell_4}{I_4} = -\frac{6A_3a_3}{\ell_3I_3} - \frac{6A_4b_4}{\ell_4I_4}$$

$$n = 4,\ \frac{M_3\ell_4}{I_4} + 2M_4\left(\frac{\ell_4}{I_4}+\frac{\ell_5}{I_5}\right) + \frac{M_5\ell_5}{I_5} = -\frac{6A_4a_4}{\ell_4I_4} - \frac{6A_5b_5}{I_5\ell_5}$$

$$M_4\ell_4 + 2M_5\left(\ell_5+\ell_6\right) + M_6\ell_6 = 0$$

Case I. Ends w/variable fixity

$$\theta_o = 0$$

If

$$\frac{M_o\ell_1}{I_1} = \frac{M_1\ell_1}{2I_1} - \frac{3A_1b_1}{\ell_1I_1}$$

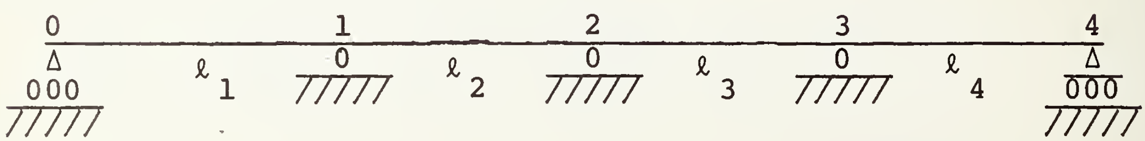
$$
\begin{bmatrix}
\frac{\ell_1}{I_1} & 2\left(\frac{\ell_1}{I_1}+\frac{\ell_2}{I_2}\right) & \ell_2/I_2 & 0 & 0 \\
0 & \frac{\ell_2}{I_2} & 2\left(\frac{\ell_2}{I_2}+\frac{\ell_3}{I_3}\right) & \frac{\ell_3}{I_3} & 0 \\
0 & 0 & \frac{\ell_2}{I_2} & 2\left(\frac{\ell_3}{I_3}+\frac{\ell_4}{I_4}\right) & \frac{\ell_4}{I_4} \\
0 & 0 & 0 & \frac{\ell_3}{I_3} & 2\left(\frac{\ell_4}{I_4}\right) \\
0 & 0 & 0 & 0 & \frac{\ell_4}{I_4}
\end{bmatrix}
\begin{bmatrix} M_o \\ M_1 \\ M_2 \\ M_3 \\ M_4 \end{bmatrix}
= -6
\begin{bmatrix}
\left(\frac{A_1 a_1}{\ell_1 E_1 I_1} + \frac{A_2 b_2}{\ell_2 I_2}\right) \\
\left(\frac{A_2 a_2}{\ell_2{}_2} + \frac{A_3 b_3}{\ell_3 I_3}\right) \\
\left(\frac{A_3 a_3}{\ell_3 I_3} + \frac{A_4 b_4}{\ell_4 I_4}\right) \\
\frac{A_4 a_4}{I_4 \ell_4} \\
\frac{-M_3}{2I_4} - \frac{3A_3 b_3}{\ell_3 I_4}
\end{bmatrix}
$$

Since $M_4 = 0$ if simple supported end

$M_o = 0$

Solve M_o, M_1, M_2, M_3, and M_4.

Case II. Simply supported ends



If simply supported at ends "0" and "4"

$$M_o = M_4 = 0$$

Then,

$$
E_x
\begin{bmatrix}
2\left(\frac{\ell_1}{I_1}+\frac{\ell_2}{I_2}\right) & \ell_2 & 0 \\
\frac{\ell_2}{I_2} & 2\left(\frac{\ell_2}{I_2}+\frac{\ell_3}{I_3}\right) & \frac{\ell_3}{I_3} \\
0 & \frac{\ell_2}{I_2} & 2\left(\frac{\ell_3}{I_3}+\frac{\ell_4}{I_4}\right)
\end{bmatrix}
\begin{bmatrix} M_1 \\ M_2 \\ M_3 \end{bmatrix}
= -6E_x
\begin{bmatrix}
\frac{A_1 a_1}{\ell_1 I_1} + \frac{A_2 b_2}{\ell_2 I_2} \\
\frac{A_2 a_2}{\ell_2 I_2} + \frac{A_3 b_3}{\ell_3 I_3} \\
\frac{A_3 a_3}{\ell_3 I_3} + \frac{A_4 b_4}{\ell_4 I_4}
\end{bmatrix}
$$

$$
\text{Solve}\quad \begin{bmatrix} M_1 \\ M_2 \\ M_3 \end{bmatrix} = -6 \begin{bmatrix} 2\left(\frac{\ell_1}{I_1}+\frac{\ell_2}{I_2}\right) & \frac{\ell_2}{I_2} & 0 \\ \frac{\ell_2}{I_2} & 2\left(\frac{\ell_2}{I_2}+\frac{\ell_3}{I_3}\right) & \frac{3}{I_3} \\ 0 & \frac{\ell_2}{I_2} & 2\left(\frac{\ell_3}{I_3}+\frac{\ell_4}{I_4}\right) \end{bmatrix}^{-1} \begin{bmatrix} \frac{A_1a_1}{\ell_1I_1} + \frac{A_2b_2}{\ell_2I_2} \\ \frac{A_2a_2}{\ell_2I_2} + \frac{A_3b_3}{\ell_3I_3} \\ \frac{A_3a_3}{\ell_3I_3} + \frac{A_4b_4}{I_4\ell_4} \end{bmatrix}
$$

General n spans continuous Beam Bridge with end constraints.

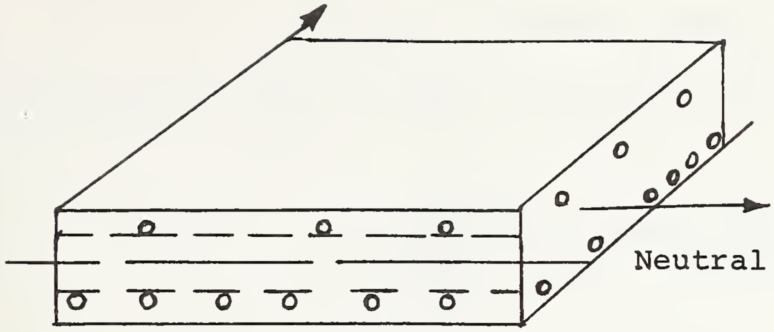
$$
\begin{bmatrix}
2\frac{\ell_1}{I_1} & \frac{\ell_1}{I_1} & 0 & 0 & \cdots & 0 & 0 & 0 \\
\frac{\ell_1}{I_1} & 2\left(\frac{\ell_1}{I_1}+\frac{\ell_2}{I_2}\right) & \frac{\ell_2}{I_2} & 0 & \cdots & 0 & 0 & 0 \\
0 & \frac{\ell_2}{I_2} & 2\left(\frac{\ell_2}{I_2}+\frac{\ell_3}{I_3}\right) & \frac{\ell_3}{I_3} & \cdots & 0 & 0 & 0 \\
0 & 0 & \frac{\ell_3}{I_3} & 2\left(\frac{\ell_3}{I_3}+\frac{\ell_4}{I_4}\right) & \frac{\ell_4}{I_4} \cdots & 0 & & 0 \\
0 & 0 & 0 & \frac{\ell_4}{I_4} & 2\left(\frac{\ell_4}{I_4}+\frac{\ell_5}{I_5}\right) \cdots & 0 & & 0 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \\
0 & 0 & 0 & 0 & \cdots\frac{\ell_{n-1}}{I_{n-1}} & 2\left(\frac{\ell_{n-1}}{I_{n-1}}+\frac{\ell_n}{I_n}\right) & \frac{\ell_n}{I_n} & 0 \\
0 & 0 & 0 & 0 & \cdots 0 & 0 & \frac{\ell_n}{I_n} & \frac{2\ell_n}{I_n}
\end{bmatrix}
\begin{bmatrix} M_o \\ M_1 \\ M_2 \\ M_3 \\ M_4 \\ \vdots \\ M_{n-1} \\ M_n \end{bmatrix}
$$

A_1b_1/ℓ_1I_1

$$
= -6 \left\{ \begin{matrix} \dfrac{A_1 a_1}{\ell_1 I_1} + \dfrac{A_2 b_2}{\ell_2 I_2} \\[2ex] \dfrac{A_2 a_2}{\ell_2 I_2} + \dfrac{A_3 b_3}{\ell_3 I_3} \\[2ex] \dfrac{A_3 a_3}{\ell_3 I_3} + \dfrac{A_4 b_4}{\ell_4 I_4} \\ \vdots \\ \dfrac{A_{n-1} a_{n-1}}{\ell_{n-1} I_{n-1}} + \dfrac{A_n b_n}{\ell_n I_n} \\[2ex] \dfrac{A_n a_n}{\ell_n I_n} \end{matrix} \right\}
$$

Anisotropic Composite Deck

$$\sigma_x = E_x' \varepsilon_x + E'' \varepsilon_y$$
$$\sigma_y = E_y' \varepsilon_y + E'' \varepsilon_x$$
$$\Gamma_{xy} = G\gamma_{xy}$$
$$D_x = \frac{E_x' h^3}{12}$$
$$D_y = \frac{E_y' h^3}{12}$$
$$D_1 = \frac{E'' h^3}{12}$$
$$D_{xy} = \frac{Gh^3}{12}$$



$$D_x \frac{\partial^4 \omega}{\partial x^4} + 2(D_1+2D_{xy}) \frac{\partial^4 \omega}{\partial x^2 \partial y^2} + D_y \frac{\partial^4 \omega}{\partial y^4} = q$$

$$H = D_1+2D_{xy}$$

For isotropy,

$$E_x' = E_y' = \frac{E}{1-\nu^2} \; . \quad E'' = \frac{\nu E}{1-\nu^2} \; . \quad G = \frac{E}{2(1+\nu)}$$

$$\therefore \; D_x = D_y = \frac{Eh^3}{12(1-\nu^2)}$$

$$H = D_1+2D_{xy} = \frac{Eh^3}{12(1-\nu^2)}$$

For reinforced concrete beam,

$$n = E_s/E_c \quad , \quad \nu_c \approx \frac{E''}{E_x'E_y'}$$

For two-way reinforced concrete,

$$D_x = \frac{E_c}{1-\nu_c{}^2}\left[I_{cx}+(n-1)I_{sx}\right] = \frac{E_c}{1-\nu_c{}^2}\left[I_{cx}+\left(\frac{E_s}{E_c}-1\right)I_{sx}\right]$$

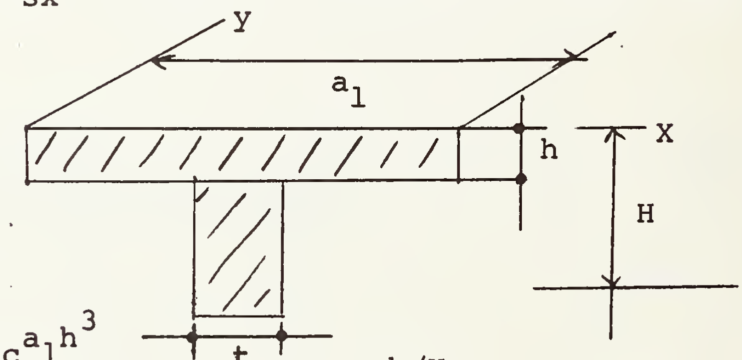
$$D_y = \frac{E_c}{1-\nu_c{}^2}\left[I_{cy}+(n-1)I_{sy}\right]$$

$$D_1 = \nu_c\sqrt{D_xD_y}$$

$$D_{xy} = 1-\nu_c\ /_2\ \sqrt{D_xD_y}$$

where I_{cx} = moment of inertia of slab material

I_{sx} = moment of inertia of steel reinforced rods



$$D_x = \frac{E_c a_1 h^3}{12(a_1 - t + \alpha^3 t)} \qquad \alpha = h/H$$

$$D_y = \frac{E_c I}{a_1}$$

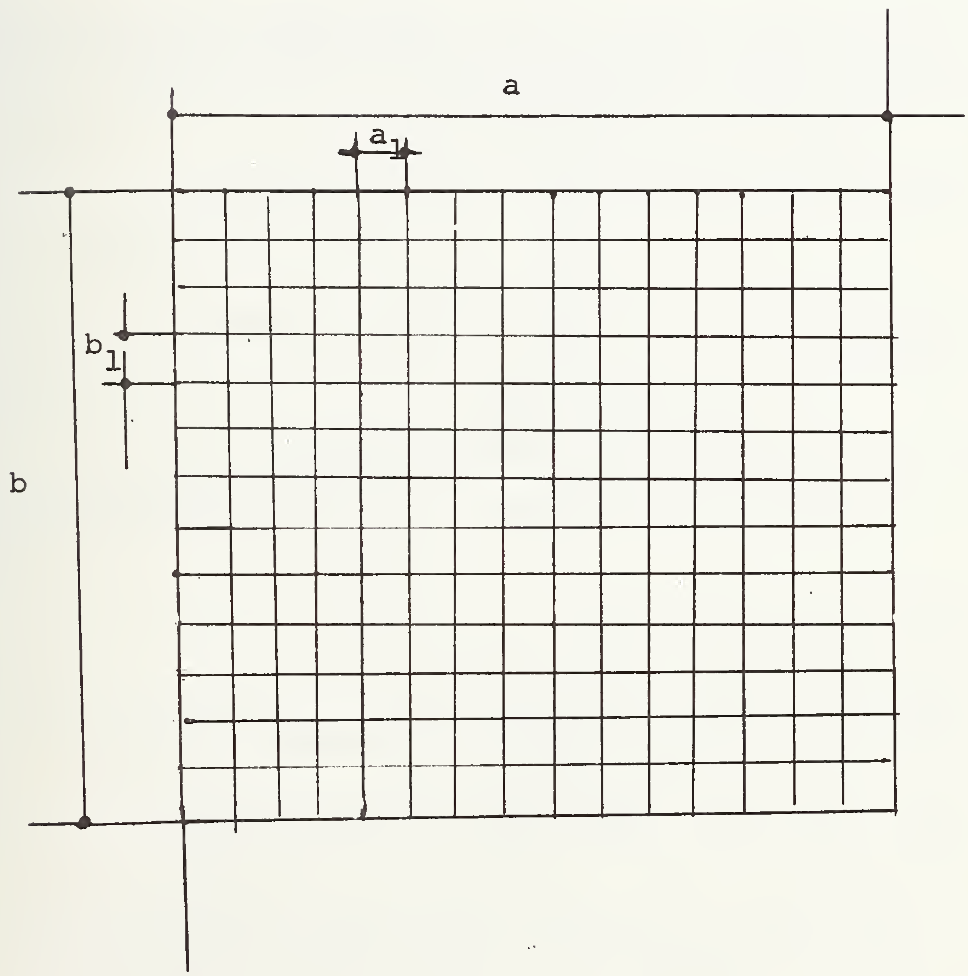
$$D_1 = 0$$

I = moment of inertia of a Tee section of width a_1

$$D_x = \frac{B_1}{b_1} \qquad\qquad H = \sqrt{D_x D_y}$$

$$D_y = \frac{B_2}{a_1}$$

B_1 , B_2 are flexural rigidities.



Calculate the beam's sectional modulus

Steel Girder

Calculate the geometric centroid, i.e., neutral axis.

Given,

b = effective width

t_1 = concrete deck thickness

I_s = moment of inertia for WF beam $\underline{in^4}$

A_s = sum of the cross sectional area of reinforced steel bars Bars

A_I = I Beam's Area

$$C_1 = \frac{\Sigma A_i C_i \text{ (Sum of each cross section Area centroid distance)}}{\text{Total Cross Sectional Area}}$$

A_i = Area of Material i

C_i = Centroid Distance with Reference to Base Line of Material i

$$\therefore C_1 = \frac{b_1 t_1 \cdot \frac{t_1}{2} + A_s \cdot C_s + A_I \cdot C_I + b_2 t_2 (\frac{t_2}{2} + C_p)}{\text{Area of Concrete } (b_1 t_1) + b_2 t_2 (\text{coverplate} + A_I (\text{WF=Beam})) \text{ st.}}$$

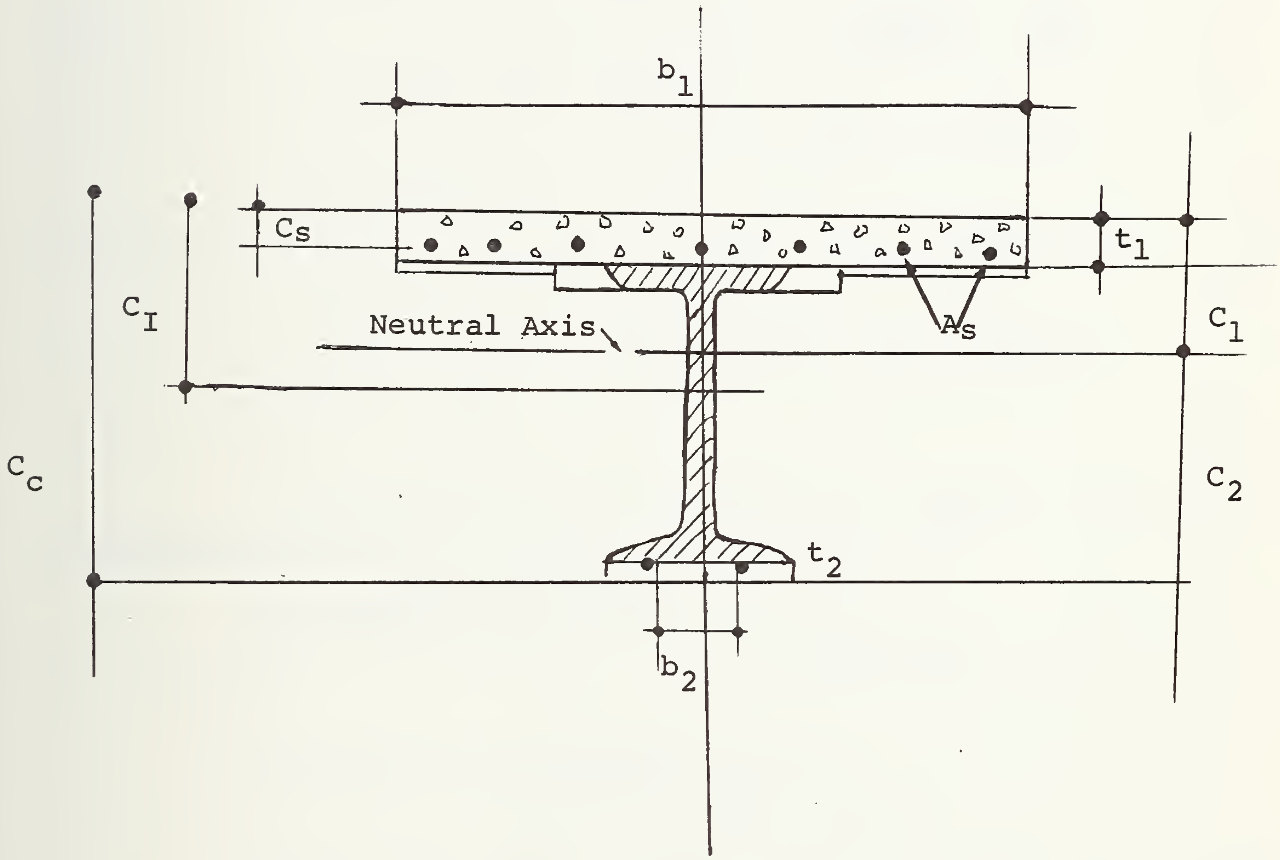
Combined moment of inertia,

$$I_c = \frac{1}{12} b_1 t_1^3 + b_1 t_1 \cdot (c_1 - \frac{t_1}{2})^2 + I_{st.bars} + A_s (C_1 - C_s)^2 +$$

$$I_s + A_I (C_I - C_1)^2 + \frac{1}{12} b_2 t_2^3 + b_2 t_2 \cdot (C_c - C_1)^2$$

$$Z_{c_1} = \frac{I_c}{c_1}$$ Sectional modulus for beam's upper element

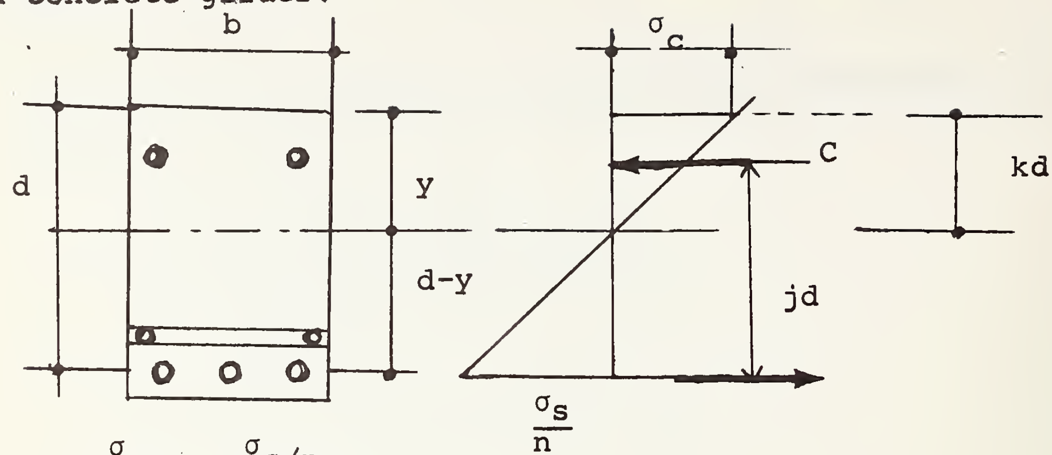
$$Z_{c_2} = \frac{I_c}{c_2}$$ Lower sectional modulus of beam



where C_I = distance of WF beam centroid to the base.

Concrete Girder

For a concrete girder:



$$\frac{\sigma_c}{kd} = \frac{\sigma_s/n}{d-kd}$$

$$(1-k)/_k = {}^{\sigma_s}/_{n\sigma_c}$$

$$n = {}^{E_s}/E_c = 7$$

$$bkd\,\frac{kd}{2} = nA_s\,(d-kd)$$

$p = {}^{A_s}/bd$ Area ratio of steel to that for concrete above the steel reinforcing bars

$$k = \sqrt{2pn+(pn)^2} - pn$$

$$C = \text{compressive force}$$
$$= \left(\frac{\sigma_c}{2}\right) bkd$$

$$T = \sigma_s A_s = \text{tensile force}$$

$$M_s = \sigma_s A_s jd, \qquad M_u = \psi\left[A_s f_y d\left(1-0.6p\,\frac{f_y}{f_c}\right)\right]$$

$$n = \frac{E_s}{E_c} = \frac{30x.0^6}{4.3x10^6} \cong 7 \qquad 0.9 \text{ mod. factor}$$

$$M_c = \frac{\sigma_c}{2} b(kd)\ (jd) = \frac{1}{2} \sigma_c\ kjbd^2$$

M_s & M_c are then the bending moments of a concrete beam

To determine $n = \frac{\sigma_s}{\sigma_c}$:

σ_c the compressive concrete stress is evaluated, or is assigned, and is defined as

$$\sigma_c = \frac{\sigma_s}{n}$$

where

σ_c & n are known, and

σ_s is computed.

Find the neutral axis of the reinforced concrete beam, i.e.,

$$k = \left[\sqrt{2pn+(pn)^2} - pn\right]$$

where $p = \frac{A_s}{bd}$

calculate kd, i.e., neutral axis from the base of composite beam

M_B is bending moment in the beam at any point along the beam, and

Bending stress $= \frac{M_B}{Z_{ec}}$, where

Z_{ec} = equivalent bending sectional modulus for concrete

Now $\quad Z_{es}$ = equivalent sectional modulus for steel section

$$EI = \left[E_c I_{g/s} + E_s I_s\right] \Big/ \left[1 + R_m\right]$$

I_g = moment of inertia of gross concrete section about the controid axis, neglecting the reinforcement steel, and

R_m = ratio of maximum design dead load moment to maximum design total load moment, always positive.

DESCRIPTION OF ANALYTIC METHODOLOGY DEVELOPED

The objectives of the investigation of analytic methods was to attempt to develop and provide a practical means for predicting the long term effects due to heavy truck loadings. The methodology which is based upon the use of a traffic simulator is inadequate for long term applications, for example, 50-year life spans. In order to utilize such a simulator small time samples, for example, a continuous two-week sample, must be taken for traffic distributions anticipated for a given period of time. It is then necessary to run several such samples, varying the time dependent parametric traffic data. The present version of BRIGLD1 can be satisfactorily operated at up to a 720 to 1 real-time to computer use time compression ratio, as compared to the 2 to 1 of the original program. However, even at this increased rate a total of 5 hours of CP time is required merely to generate the loads, without any consideration of the stress calculations. The dynamic stress calculations are far more complex and require a very small time interval. Hence, the CP time required to calculate the response of a bridge to the prescribed loads will be far greater than that necessary to generate the loads. Present range from 6 to 1, to 30 to 1 for real time compression to perform the stress calculations. This implies the need for an additional 112 to 560 hours of CP time. The main cause is the integration interval size. The load generator is essentially a pseudo-truck load event simulator and will integrate motion at a maximum interval. This interval is far too large to be satisfactory for the calculation of a bridge's structural response to a load. Consequently, the structural program moves the axle defined loads over the deck at a necessarily small interval, independent of the simulator's incremental interval. The stresses are calculated at each of these time points.

The two programs are independent of each other, that is, stand alone. They can be linked together or run totally

independently. The output of the load generator may be used for other purposes and the input to the structural program may be derived from other sources. Additionally, if a pseudo bridge length of sufficient magnitude, which would include all bridge lengths to be analyzed structurally, is used by the simulator, there is no need to re-run the load generator for shorter bridge lengths. The structural program will properly use the one set of data, recorded on magnetic tape, for the analysis of all bridge lengths equal to or less than the original pseudo bridge length used by the simulator, for the highway defined by the simulator's data base.

While the above defined approach has increased the useability of the BRIGLD1 Simulator and the orginal concept, which caused its creation, this approach is not economically a feasible approach to provide insight into all possible forms of significant truck platoon events or into long term accumulated effects.

A more practical approach is to ignore traffic simulation, merely generate each unique platoon event and evaluate its effect upon a bridge. Subsequently, generate long term effects by operating on each single event effect with the incidence of the event over the period of interest. However, even this approach cannot be practically applied against the number of potential platoon events, as is discussed below.

Presently, the simulator has a total of 10 truck types defined in its present highway traffic data base. This is less than the actual total number of types in existence, for example, the set of truck types utilized in the far western states. However, using the 10 types, as defined below:

1.	Type 2D	with one length	= 1
2.	Type 3	with one length	= 1
3.	Type 2S1	with three lengths	= 3
4.	Type 2S2	with three lengths	= 3
5.	Type 3S2	with two lengths	= 2
	We have a total of		10 elements

Assuming, that 10,000 lb load increments will normally provide a significant variation in the response of a bridge, and that no significant response can be expected below a gross load of 10,000 lb, the above number of elements increases to the following:

1.	Type 2D, 1 x 2 wt classes	= 2
2.	Type 3, 1 x 3 " "	= 3
3.	Type 2S1,3 x 3 " "	= 9
4.	Type 2S2,3 x 15 " "	=15
5.	Type 3S2,2 x 8 " "	=16
		45 elements

If the effects due to speed are considered in an essentially minimal manner, that is, that 20 mph speed increments will provide a significance threshold in the dynamic behavior of a bridge and that a lower speed limit of 20 mph is used, the above number of elements increase to the following:

1.	Type 2D, 2 x 3 speed classes	= 6
2.	Type 3, 3 x 3 " "	= 9
3.	Type 2S1, 9 x 3 " "	=27
4.	Type 2S2,15 x 3 " "	=45
5.	Type 3S2,16 x 3 " "	=48
		135 elements

Simplistic approximation of the number of unique single truck platoon load events may be determined by taking all combinations

of the indicated elements for platoon sizes of interest. To provide a reasonable basis for platoon definition, it will be assumed that a platoon continues to exist as long as the bridge is excited by a truck load. Hence, a truck platoon size of six trucks appears to be a maximum possibility. If all unique platoon events were to be determined, then, it would be necessary to consider spatial configurations of the component trucks, that is, spatial or positional permutations. This leads to an immense number. Merely considering combinations indicates the following number of unique platoons (not platoon events):

1.	Single Truck Platoons:	135
2.	Double Truck Platoons:	9,045
3.	Triple Truck Platoons:	400,995
4.	Quadruple Truck Platoons:	13,232,835
5.	Quintuple Truck Platoons:	346,700,277
6.	Sextuple Truck Platoons:	6,356,839,335
		6,717,182,522

6,717,182,522 unique truck platoons is far too many to allow practical evaluation of the response of a bridge to each platoon, ignoring positional permutations, especially via a traffic simulator.

Hence, a critical analysis of the definition of significant events, that is, significant truck loading effects, must be made and an attempt made to reduce the total number of unique truck platoons load events to a manageable size.

A more realistic approach to providing a long term cumulative damage estimate to bridges, is to start with a definition of significant stress class intervals and dynamic stress range class intervals to provide a basic definition of significant events to a bridge. A reasonable basis would be to use 10 percent or 10 intervals of maximum stress. This leads to a total 10 types of maximum stress events.

Having defined the significant event it is then necessary to define the conditions which cause the event, that is, in this case the set of trucks, in terms of

1) type (including configuration and length)
2) gross weight
3) speed
4) platoon configuration

The approach to this is to predetermine which combinations are equivalent under constant nominal structural conditions, and select a representative truck platoon load case for each 10 percent stress range interval. Each of these 10 cases can then be run on the structural analysis program to generate the specific response for each bridge of interest.

The total incidence, for any given time period, would be made up by the incidence of each truck platoon element in each 10 percent equivalence set over the time period of interest. This reduces the structural calculations and the load generation. It imposes the need to

1. Segregate the different truck platoon events into the 10 percent stress interval equivalence sets. This, in itself, is a very large job, although of a non-recurring nature.

2. Calculate the incidence of each separate truck platoon event in each equivalence set and sum these events over each equivalence set to determine the total incidence in each 10 percent stress interval.

While the foregoing provides a better basis for generating long term histograms, of stress classes, it is still almost an impossible task to form the necessary equivalence classes

of truck platoon load events. Hence, another approach was conceived that appeared to have significant merit and was of a general nature, which would allow broad utilization.

This approach is predicated upon the concept that each axle has a stress signature and that a total truck signature, or platoon signature, is actually a composite of the individual axle stress signatures. Further, it is predicated that the amplitude is a first order effect of the axle weight and the duration is a first order effect of the axle speed.

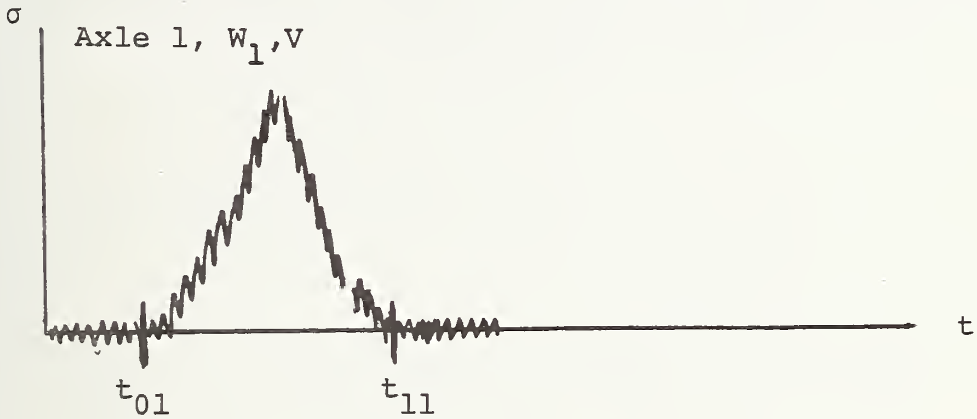
Using such an hypothesis, traffic simulation can be eliminated and the structural analysis program need only be utilized to generate a minimum set of single axle events, for example, at increments of 4000 lbs in weight from 4000 lbs to 40,000 lbs on the basis of a speed normalized duration. If necessary, speeds of 10 mph, 50 mph and 90 mph could be imposed to form an interpolative basis for speed, rather than using an estimation from the single normalized set. This would require 60 cases to be run on the stress program for each bridge to be analyzed, considering two lanes.

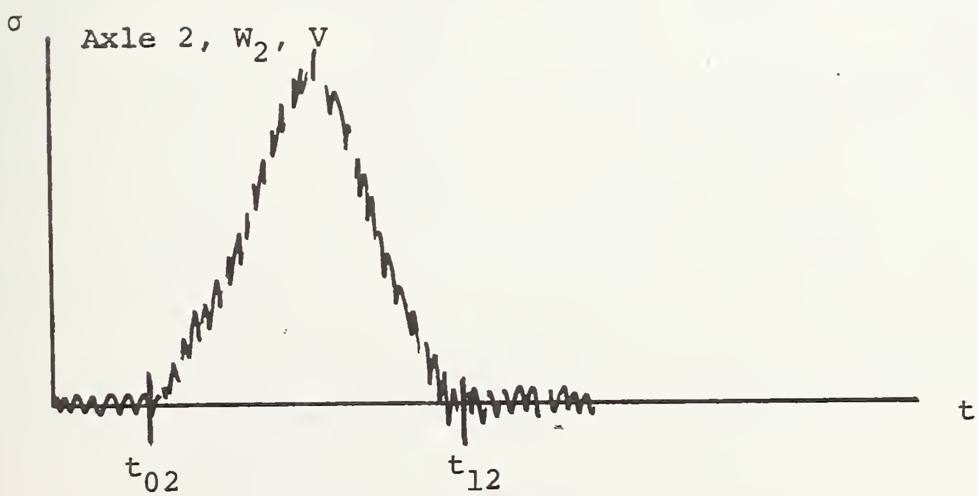
On the basis of such axle weight speed stress curves, a composite curve may be formed for a total truck from the set of axle stress curves which represent its component axles. These individual curves become essentially additive as a function of the axle distance, i.e., lag time,

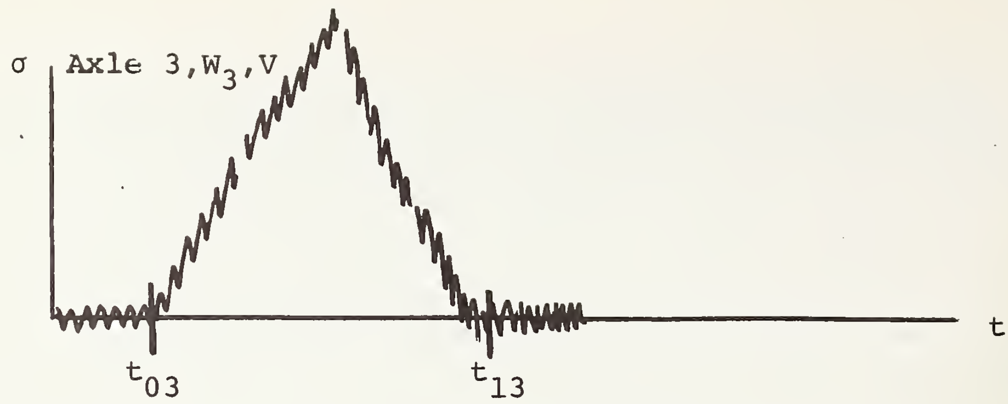
$$\tau_{AB} = \frac{d_{AB}}{V}$$

$$\tau_{AC} = \frac{d_{AB}+d_{BC}}{V}$$

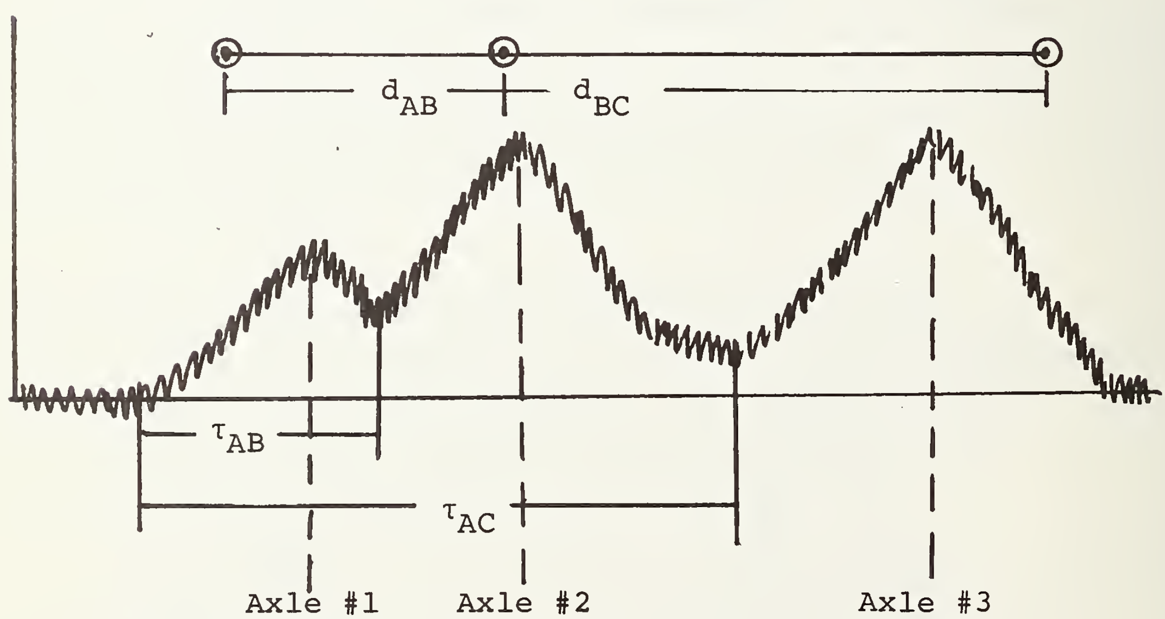
Hence, the second axle begins to effect the bridge τ_{AB} seconds after the first axle's effect occurs, and the third axle begins, similarly, τ_{AC} seconds after the first axle. The stress imposed at $t_0 + \tau_{AB}$ is then the reference for axle #2's stress curve, that is, the stress curve for the second axle is added to the stress at time $t_0 + \tau_{AB}$. Similarly, the stress for the third axle is added to the stress remaining on the bridge beam at time $t_0 + \tau_{AC}$ seconds, that is, given the axle curves:







The total approximate truck stress curve is then formed as a composite of these single axle curves, i.e.,



This eliminates the need for evaluating each truck's effect on a bridge through the structural analysis program.

Given a particular truck, i.e., distances to each axle from the front axle, speed, total weight and fraction of weight at each axle, a composite stress curve can be generated from a set of such single axle stress curves. The steps to construct such a composite stress curve are as follows:

1. Select four single axle stress curves, for each axle of the given truck, i.e.,

$$\sigma_{ij}(t) = F(V_i, W_j, t)$$

$$\sigma_{ij+1}(t) = F(V_i, W_{j+1}, t)$$

$$\sigma_{i+1j}(t) = F(V_{i+1}, W_j, t)$$

$$\sigma_{i+1,j+1}(t) = F(V_{i+1}, W_{j+1}, t)$$

where

$$V_i \le V \le V_{i+1},\ W_j \le W \le W_{j+1}, t = \text{time}$$

and, V and W are the speed and weight respectively for each of the given truck's axles.

2. Linearly interpolate for $\sigma(V,W_j,t)$ and $\sigma(V,W_{j+1},t)$ from the selected single axle stress curves for each axle of the given truck.

3. Linearly interpolate between $\sigma(V,W_j,t)$ and $\sigma(V,W_{j+1},t)$ for $\sigma(V,W,t)$ for each axle of the given truck.

4. Establish a base stress curve with $\sigma_A(v,W,t)$ for the first axle, A.

5. Calculate, as a function of distance between the axles and the given truck's speed, the lag time for each rear axle, i.e.,

$\tau_B = \frac{d_{AB}}{V}$ where A represents the front axle, B the 2nd axle, d_{AB} the distance between A and B, and V the speed of the truck. For a third axle,

$$\tau_C = \frac{d_{AC}}{V} .$$

6. The second axle's stress curve, $\sigma_B(V,W,t)$ is then added to the base curve $\sigma_A(V,W,t)$ translated by τ_B, i.e.,

$$\sigma_{Truck} = \sigma_A(V,W,t) + \sigma_B(V,W,t+\tau_B)$$

Similarly, the third axle, if it exists, is added to the base curve to form the final truck stress curve, i.e.,

$$\sigma_{Truck} = \sigma_A(V,W,t)+\sigma_B(V,W,t+\tau_B)+\sigma(V,W,\tau_C)$$

Truck platoons can further be approximated in the same manner as the individual truck stress curves, without simulating each possible platoon event, in a similar manner. Lateral, or lane adjacent, formed platoons can be approximated by considering the load imposed on each beam by any given axle load in the same manner as described above. This imposes the need to retain the stress curve for each beam in a bridge for each of the axle's needed, for example, the 60 at 4000# increments. If a bridge has eight beams then a total number of stress curves required, for one sample point per beam, in the "library" of axle stress curves for that bridge would be 480 curves. This approach provides a realistic and minimal computation method for the generation of unique truck platoon events on a bridge.

The statistics of truck platoon events, per unique event, could then be imposed for a long term prediction of stress level incidence.

For further simplicity dual axles may be represented as single axles with the combined load of two real axles. At 88fps (60 mph) a lag of ~.05 sec occurs between dual axles at 4' centers and at 44fps(30 mph) a lag of ~.10 sec occurs. Resolution of field data is not good enough to completely verify the existence of a composite dual axle signature. Hence, the single axle signature representation must vary, nominally between 4000 and 40000# rather than the 2000# and 30000# which would normally be expected. This provides 10 axle signature weights at constant speed for a single position on a beam. Two nominal speed classes of 30 mph (midpoint of 10 to 50 mph interval)and 70 mph (midpoint of 50 to 90 mph interval) would produce a total of 20 stress signatures per beam position per lane. Since the structural program is designed as it is, it will simultaneously produce the stress signatures for each sample point on each beam.

In order to provide realism if felt necessary, the second axle of a dual set of axles may be included in the synthesis of the total response trace in the same manner as a rear axle as a function of speed.

In order to generate the stress data necessary to the method described in the foregoing, a simple load generator was required. It must output load data that is consistent with the present input load data specification of the structural analysis program, which was developed for BRIGLD1. All data is sequential as shown below, and in binary form, on magnetic tape,

t = time of load sampling (secs), a single value and real

Δt = time increment of load samples (secs), a single value

NEV = Event number. This number will also act as a pointer to the generated stress curve for a particular parametric triplet, that is, $\{V, W, NL\}$, it is an integer

NAXLE = 1 (integer)

NTRUCKS = 1 (integer)

LAST = A logical indicator where

1. True implies the last set of load data for a given event, or
2. False implies all load data sets except the last.

Truck Type (20): Twenty integer values are furnished in the data block. However, this parameter has no meaning for this program and all values will be set to unity.

Truck Weight (20): Twenty real values are furnished. However, the first value will be W and all other values will be set to zero.

Truck Speed (20): Twenty real values are furnished. However, the first value will be V, and all other values will be set to zero.

Truck Lane(20): Twenty integer values are furnished. However, the first value will be NNL and all other values will be set to zero.

Truck Entry Time (20): Twenty real values are furnished, all zero.

Axle Position (50): Fifty real values are furnished, the first value is X and all other values are zero.

Axle Lane (50): Fifty integer values are furnished, the first value is NNL and all others are zero.

Axle Weight (50): Fifty real values are furnished, the first value is W and all others are zero.

Travel Distance (50): Fifty real values are furnished, the first is ΔX and all others are zero.

Acceleration (50): Fifty real values are furnished, all zero.

In addition to requiring a special load event generator, a minor modification of the structural analysis program was also required. This modification allowed the generated stress data to be retained in an auxiliary storage media, magnetic tape, for processing by the program developed in this portion of the investigation, which is described in FHWA-RD-73-45 and referred to as the "Stress Histogram" program, HISGEN.

Consistent with the present form of the output of the structural analysis program, from one to three sample points per beam are allowed, for the stress trace output to tape. No sophisticated processing of the generated digital stress trace data is performed by the structural program.

The following data is passed, as a header record for each stress event, from the structural program to the histogram program:

- NEV = the event number, integer
- W = the axle weight, #, real
- V = the axle velocity, fps, real
- N_L = number of lanes, integer
- ∇t = time increment used by the structural program, real
- B_L = bridge length, ft, real
- NP(J)=number of sample points per Jth beam, integer
- NB = number of beams, integer
- NNL = Lane Number

After a header, the set of stresses, at a given time, for each sample point, 1 to 3 per beam, are output as a record. This is repeated for all time points contained in a given stress event. The next stress event repeats the above process, starting with a new header record.

$$\begin{array}{lll}\sigma(X_1,\ 1), & \sigma(X_2,\ 1), & \sigma(X_3,\ 1) \\ \sigma(X_1,\ 2), & \sigma(X_2,\ 2), & \sigma(X_3,\ 2) \\ \vdots & \vdots & \vdots \\ \sigma(X_1, N_B), & \sigma(X_2, N_B), & \sigma(X_3, N_B)\end{array}$$

where $\sigma(X_p,\ j)$ is defined as the stress, at time t, for position X_p, $1 \leq p \leq 3$, on beam j, for $1 \leq j \leq N_B$.

Stress Histogram Program (HISGEN)

The overall program developed in this portion of the project was the "Stress Histogram Program." Its function is to

1. Construct and save, on magnetic tape, time dependent digital stress traces at each sample point, per beam, for each load event, that is, each prescribed axle weight, velocity and lane. This amounts to primarily a sort of the data output by the structural analysis.

2. Construct and save, on magnetic disk, the stress trace of each truck category for each sample point on each beam. Each truck category is defined in terms of weight, velocity and lane of occupancy. These three variables must correlate with the distribution functions prescribed for these variables and input to the program, as discussed later under "Platoon Construction."

3. As a function of the given distribution functions of truck weight, velocity, lane occupancy and platoon size, construct digital platoon stress traces for each sample point, per beam.

4. From each digital platoon stress trace, per sample point, extract the maximum stress values.

5. Calculate the probability of existence of each platoon construct and, as a function of ADT, truck fractions of the traffic population, the predicted growth/decay function, and the life span desired for the bridge, estimate the number of occurrences of each platoon.

6. For each maxima stress value extracted, for each platoon, add the number of occurrences to each stress class interval in each sample point's histogram of the platoon.

7. Exhaust the set of platoons defined in the given distribution data and output the histogram data.

This program has been completely subroutined in order to allow ease for future modifications. From a logic, functional, and repetitive use point of view there was no need to use subroutines. It is only from a replacement or upgrading point of view that this approach was warranted.

Truck Trace Construction

The formation of the composite axle stress trace to synthesize the stress trace of a given truck was accomplished in a very straightforward manner. Linearity of response is assumed.

The delay time between axles was estimated as

$$\tau = \frac{\Delta AX}{V}$$

where ΔAX is the distance of any given axle from the front axle, and V is the truck's speed, fps.

The integer number of time increments, N, contained in the delay time is calculated and the fractional part of the delay time, that is, less than a full time increment determined from

$$\Delta\tau = \tau - N.\Delta t$$

A linear interpolative formula was used to approximate that portion of the axle stresses to be superimposed on the first axle's stress trace, that is, for

$$t_m \leq \tau_p < t_{mH}$$

$$\sigma_m = \sigma_m + \frac{\Delta\tau}{\Delta t}(\sigma_{pH} - \sigma_p)$$

where σ_m is from the reference on base stress trace and σ_p is from the stress trace of the axle being superimposed.

The above process is performed for each set of truck parameters defined in the input data at each sample point on each beam from the synthetically generated stress data.

The efficient retrieval of the appropriate point trace data for each axle specified, via the truck parameters, was a larger problem than forming an approximate truck stress trace. This is discussed in the next subsection.

Point Trace Retrieval Algorithm

To determine the record within the total point trace file containing a trace representative of an axle for a given truck, with speed, weight and lane occupancy specified, the event number, or record number, is determined as follows:

N_L = given as the total number of lanes

$$N_W = \frac{W_{max} - W_o}{\Delta W} + 1$$

$$N_V = \frac{V_{max} - V_o}{\Delta V} + 1$$

where N_L, W_{max}, W_o, ΔW, V_{max}, V_o and ΔV are the same values

as used by the Synthetic Load Generator. For the given truck

V = speed is given
W = weight of axle of interest is given, and
N_{NL} = lane of occupancy is given

The record number NR is then determined from

$$N'_V = \frac{V-V_o}{\Delta V}$$

$$N_{RO} = N'_V \cdot N_W \cdot N_L$$

$$N'_W = \frac{W-W_o}{\Delta W}$$

$$N_{R1} = N'_W \cdot N_L$$

$$NPTS = \sum_{j=1}^{NB} N_{p(j)}$$

$$N_{R2} = (N_{RO} + N_{R1} + N_{NL})\ NPTS$$

$$N_{R3} = N_{R2} + \sum_{p=1}^{j-1} (NP(p)) + i$$

where

NP(p) is the number of sample points on the p^{th} beam and i is the sample point index at the sample point of interest on th j^{th} beam.

Platoon Construction

In order to apply the foregoing, the platoon composition must be defined and be constructable, that is, in terms of constructing its truck content and spatial configuration, its

stress curve and the incidence of occurrence. A basis for providing a means to define the platoons would be as follows, as an example:

1. Assume two speed class intervals, as indicated previously, for each truck type, that is, lo-speed (0-50) and hi-speed (50 and above),

2. Assume nine truck configurations,

3. Assume spatial permutations have no effect, since stresses are in the elastic range and are linear and additive, and that a worst case platoon positional configuration will be sufficiently representative of anticipated stresses for spatial permutations of the given platoon components,

4. Assume single weight for each truck category, that is, maximum anticipated,

5. Assume a maximum platoon size of six trucks,

This constrains the set of platoon elements to 18 and the total number of load events is determined as:

Platoon Size	Number of Different Platoons	Truck Population
1	18	18
2	153	306
3	816	2448
4	3060	12240
5	8568	42840
6	18564	111384
	31179	169236

This implies 31179 unique load events involving a truck population of 169236.

The criteria utilized to form the platoon spatial configuration should be realistic, for example,

1. Slowest vehicle(s) in the right lane
2. Minimum headway distance between vehicles

For this case, it then appears that 31179 platoons would need to be evaluated, that is, their stress effect determined and the incidence of each platoon determined.

The construction of the estimated stress response of each beam would be determined as indicated previously for trucks. Multiple lane occupancy is taken care of by the addition of each sample point's response for each truck due to lateral effect. Time lag effects are included in the same manner as shown previously for truck trace construction.

In order to determine the incidence of each platoon configuration's stress response, certain statistics regarding the traffic must be available or estimated from best available data, that is,

1. Average daily traffic (ADT)

2. Percent of traffic that is truck traffic, P_T

3. Distribution of significant truck types in total truck population,

$$[P_{T1}, P_{T2}, P_{T3}, P_{T4}, P_{T5}, P_{T6}, P_{T7}, P_{T8}, P_{T9}]$$

where $\sum_{i=i}^{9} P_{Ti} = 1$, for this example.

4. Distribution of velocity population for each type, for example, for two class intervals,

$$[(P_{V1},P_{V2})_{T1}, (P_{V1},P_{V2})_{T2}, (P_{V1},P_{V2})_{T3}, (P_{V1},P_{V2})_{T4},$$

$$(P_{V1},P_{V2})_{T5}, (P_{V1},P_{V2})_{T6}, (P_{V1},P_{V2})_{T7}, (P_{V1},P_{V2})_{T8},$$

$$(P_{V1},P_{V2})_{T9}]$$

where $\sum_{i=i}^{2} (P_{Vi})_{Tj} = 1.$

5. Distribution of platoon population by configuration, that is, trailing or passing

$$\left\{P_{NL1}, P_{NL2}\right\},$$

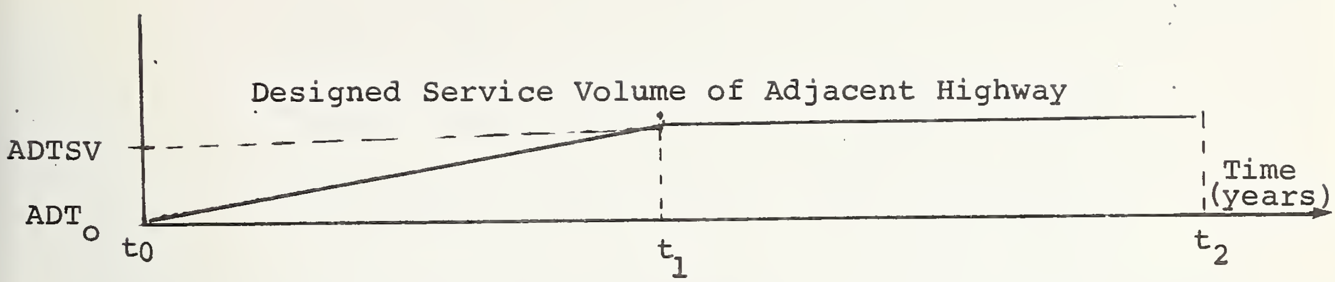
where $\sum_{i=1}^{2} P_{NLi} = 1$

6. Distribution of platoon size in total platoon population

$$[P_1, P_2, P_3, P_4, P_5, P_6]$$

where $\sum_{i=i}^{6} P_i = 1.$

7. A growth or decay function for long term growth or decline. An arbitrary function can be established to provide a mathematical basis for this function. However, a more realistic approach is to use, for now, a linear approximation between current estimated ADT and the designed daily service volume for the relevant section of highway, at the estimated point in time that the highway will reach its designed daily service volume. From that point assume the volume to remain constant for the life span of the bridge, for example,



The total estimated traffic is then

$$T_r = 365 \left[\frac{(t_1 - t_o)}{2} (ADT_o + ADT_{SV}) + (t_2 - t_1) ADT_{SV}\right]$$

where t_o = beginning of time in years

t_1 = point, in years, service volume of highway reached (estimated)

t_2 = total, in years, service life of bridge desired

ADT_o = average daily traffic initially

ADT_{SV} = average daily traffic at design service volume of highway

Lacking statistical data and a rational basis for predicting the distribution of a given truck type over the population of each platoon's population, it will be assumed that the distribution of truck types over each platoon's population is the same as over the total truck population.

If the total traffic for the period of interest is T_r and the percent of trucks in that population is P_T then the total estimated truck population over the period of interest, T_P, is

$$T_T = \text{Total Truck Population} = P_T \cdot T_r.$$

The total truck population in each platoon's population is then

$$T_{P1} = T_P \cdot P_1$$

$$T_{P2} = T_P \cdot P_2$$

$$T_{P3} = T_P \cdot P_3$$

$$T_{P4} = T_P \cdot P_4$$

$$T_{P5} = T_P \cdot P_5$$

$$T_{P6} = T_P \cdot P_6$$

The total of each type truck in each platoon's population is:

$$T_{P1j} = T_{P1} \cdot P_{Tj} \text{ for } 1 \leq j \leq 9,\ j = \text{type}$$

$$T_{P2j} = T_{P2} \cdot P_{Tj} \quad '' \quad '' \quad ''$$

$$T_{P3j} = T_{P3} \cdot P_{Tj} \quad '' \quad '' \quad ''$$

$$T_{P4j} = T_{P4} \cdot P_{Tj} \quad '' \quad '' \quad ''$$

$$T_{P5j} = T_{P5} \cdot P_{Tj} \quad '' \quad '' \quad ''$$

$$T_{P6j} = T_P{}^6 \cdot P_{Tj} \quad '' \quad '' \quad ''$$

The total of each velocity class of each type truck in each platoon's population is:

$$T_{P1jk} = T_{P1j} \cdot P_{Vk} \text{ for } 1 \leq k \leq 2,\ k = \text{velocity class}$$

$$T_{P2jk} = T_{P2j} \cdot P_{Vk} \quad '' \quad '' \quad '' \quad ''$$

$$T_{P3jk} = T_{P3j} \cdot P_{Vk} \quad '' \quad '' \quad '' \quad ''$$

$$T_{P4jk} = T_{P4j} \cdot P_{Vk} \quad \text{for } 1 \leq k \leq 2,\ k = \text{ velocity class}$$

$$T_{P5jk} = T_{P5j} \cdot P_{Vk} \quad " \quad " \quad " \quad "$$

$$T_{P6jk} = T_{P6j} \cdot P_{Vk} \quad " \quad " \quad " \quad "$$

The determination of the incidence of single truck events is straight forward, that is, the calculation of T_{P1jk} given the type; and velocity class k.

While the above provides the incidence of each j type and k velocity class in each platoon's population, it does not provide for the incidence of each platoon's configuration of size greater than one, that is, given a particular set of trucks what is the incidence of that specific platoon.

For two truck events the incidence of a specific event, that is, for a truck of type p and velocity class a, and for a truck of type q and velocity class b, whose composite stress curve has just been generated, is estimated as

$$T_{P2\ (p,a)(q,b)} = \left(\frac{T_{P2pa}}{T_{Pa}}\right) T_{P2qb}$$

This value then becomes the incidence of the platoon stress traces found in the composite stress curve for the (p,a)(q,b), 2 component, platoon. It is assumed that each element, that is, type and velocity, will pair with itself to form a 2 element platoon.

It becomes easier to work with the probabilities for platoons of size 3 and larger than with raw incidence values, for example,

$$P_{3jk} = \frac{T_{P3jk}}{T_{P3}} \quad \text{for all j and k}$$

$$P_{4jk} = \frac{T_{P4jk}}{T_{P4}} \quad \text{for all j and k}$$

$$P_{5jk} = \frac{T_{P5jk}}{T_{P5}} \quad \text{"} \quad \text{"} \quad \text{"}$$

$$P_{6jk} = \frac{T_{P6jk}}{T_{P6}} \quad \text{"} \quad \text{"} \quad \text{"}$$

Utilizing the joint probability of occurrence for determining the probability that three different trucks will occur in a single event, then

$$P_{3(p,a)(q,b)(r,c)} = P_{3pa} \cdot P_{3qb} \cdot P_{3rc}$$

Hence, given a composite 3 truck platoon stress response curve for trucks defined as

1. j = p and k = a
2. j = q and k = b
3. j = r and k = c

then the incidence of this platoon event becomes

$$T_{3(p,a)(q,b)(r,c)} = T_{P3} \ (P_{3pa} \cdot P_{3qb} \cdot P_{3rc})$$

Similarly, for a four element platoon:

1. j = p and k = a
2. j = q and k = b
3. j = r and k = c
4. j = s and k = d

and $T_{4(p,a)(q,b)(r,c)(s,d)} = T_{P4}(P_{4pa} \cdot P_{4qb} \cdot P_{4rc} \cdot P_{4sd})$

for a five element platoon:

1. j = p and k = a
2. j = q and k = b
3. j = r and k = c
4. j = s and k = d
5. j = t and k = e

and

$$T_{5(p,a)(q,b)(r,c)(s,d)(t,e)} = T_{P5}(P_{5pa} \cdot P_{5qb} \cdot P_{5rc} \cdot$$

$P_{5sd} \cdot P_{5te})$,

and for a six element platoon:

1. $j = p$ and $k = a$
2. $j = q$ and $k = b$
3. $j = r$ and $k = c$
4. $j = s$ and $k = d$
5. $j = t$ and $k = e$
6. $j = u$ and $k = f$

and

$$T_{6(p,a)(q,b)(r,c)(s,d)(t,e)(u,f)} = T_{P6}(P_{6pa} \cdot P_{6qb} \cdot P_{rc} \cdot P_{6sd} \cdot P_{6te} \cdot P_{6uf})$$

Stress Range Determination

The stress maxima are then determined, for each platoon's stress trace. The proper class interval for each sample point's histogram are then determined for each maximum stress point and the platoon's incidence is then added into each of the appropriate class intervals. The entire process is repeated until all platoon parameters have been varied as specified in the input data and all combinations of these have been exhausted.

Hence, the foregoing provides a synthetic means of generating long term stress histograms in a reasonably efficient manner and on a sound structural analysis basis. Obviously, as such an approach is utilized increased learning will occur and improvements in it can be made, for example, increased refinement of truck categories and platoon definitions, if economics and efficiency allow it.

The implemented frequency formulae, to determine the incidence of a given platoon, are as follows:

$$T_P = \frac{T_T}{\sum_{n=1}^{N} nP_P(n)}$$

where T_T is the total truck traffic as defined earlier, N is the largest platoon size, and $P_P(n)$ is the probability of occurrence of a platoon of size n in the total platoon population. This distribution must be furnished from field data.

The probability of occurrence of a truck, out of the total truck population, in a platoon of size n is

$$P_T(n) = \frac{n\, P_P(n)}{\sum_{n=1}^{N} nP_P(n)}$$

Given the probability of existence for each truck of a platoon of size n, based on type/weight and velocity, as previously discussed, that is,

$$\left\{P_1,\ P_2,\ \ldots,\ P_n\right\}$$

The probability of each element of the set, truck in the platoon, existing in a platoon of size n, out of the total truck population is determined from

$$\begin{aligned} P_{1n} &= P_1 \cdot P_T(n) \\ P_{2n} &= P_2 \cdot P_T(n) \\ &\vdots \\ P_{nn} &= P_n \cdot P_T(n) \end{aligned}$$

The probability of all the specified trucks coexisting in a platoon of size n is

$$P_{gn} = P_{1n} \cdot P_{2n} \cdot \ \ldots\ P_{nn}$$

where g is the gth set.

and the incidence of occurrence is then

$$I_{gn} = P_{gn} \cdot T_p$$

Verification of the correctness of the calculations can be made by comparing the given distributions, $P_{P(n)}$, against the calculated occurrences, that is,

$$\sum_{g=1}^{Q} I_{gn} = T_P \cdot P_P(n)$$

The class intervals of the sample points of interest containing the stress maxima from the composite traces, for each of the sample points, are then incremented by I_{gn}.

To retrieve the individual truck stress traces, for forming the platoon stress traces, which are a function of the sample point of interest, beam of interest, lane of occupancy, speed and weight, the record number of the trace is determined from

$$NR = i + NPS + NPTS \left\{ [(k_T - 1)\ DN_V + (k_V - 1)]NL + (k_L - D) \right\}$$

where

i = sample point index on given beam, j

$$NPS = \sum_{p=1}^{j-1} NP(p)$$

$$NPTS = \sum_{j=1}^{NB} NP(j)$$

KL is the given lane index,

KV is the given speed index,

KT is the given truck category index

N_V = total number of velocity classes

N_L = total number of lanes

Application of the Approach

In order to apply the foregoing approach, it is necessary to utilize the three previously described computer programs, i.e.,

1. The synthetic load generator (SYNGEN) to generate single axle load events,

2. The dynamic stress analysis program (BRGSTRS) to generate single axle stress signatures, and

3. The stress histogram program (HISGEN) to calculate platoon incidences, platoon stress ranges and construct the stress histograms.

While BRGSTRS had been tested and used on a production basis, as described in the next section, SYNGEN and HISGEN had only been tested with debug drivers and test data. A realistic test was performed using the truck traffic and bridge data for the southbound span of the bridge at I-83 and Bunker Hill Road in Maryland (3). This same bridge was also evaluated using BRIGLD1, and is described in the next section of this report.

An interesting comparison of computer time was one of the results of this testing. In using BRIGLD1 and BRGSTRS in combination, a five hour simulation of real time was performed, generating a total truck population, and their related stress time histories, of 117 trucks. The computer time used in the "go" step for each program was

1. For BRIGLD1 approximately .5 minutes, and

2. For BRGSTRS approximately 11.0 minutes.

The total time required was, then, approximately 11.5 minutes using the traffic simulation approach to achieve 5 hours of simulated time and 117 trucks.

In using SYNGEN, BRGSTRS and HISGEN in combination, a fifty year life span period was used. For this approach the period of simulated real time has no affect upon the use of computing time. The period can be 5 minutes or a thousand years and will require the same amount of computer time. The portion of this approach which affects computer useage is the generation of the single axle stress traces by BRGSTRS. The finer the mesh of speed and weight used, the more computing time is used. However, for this test case the computer time used in the "go" step for each program was

1. For SYNGEN approximately .5 minutes,
2. For BRGSTRS approximately 8.1 minutes, and
3. For HISGEN approximately 1.6 minutes.

The total time required was, then, approximately 10.2 minutes using the stress signature approach. This generated stress ranges on 9 sample points on 5 beams for the equivalent of 19399750 trucks over fifty years. In this instance 66 single axle stress traces were generated by BRGSTRS. Eleven weight values, 2 lanes, and three speeds were used by SYNGEN to create the 66 load events for BRGSTRS, i.e.,

$$58.67 \text{ fps} \leq V \leq 102.67 \text{ varied at } 22 \text{ fps, and}$$

$$2000 \text{ lbs} \leq W \leq 82000 \text{ lbs varied at } 8000 \text{ lbs.}$$

The same bridge structural data was used in this case to generate the single axle stress signatures as was used in the traffic simulation case. Nine sample points on beams 1, 2, 3, 4 and 5 were used to collect the stress data.

Instead of using weight distribution functions per truck type, HISGEN uses only the maximum anticipated weight per type to predict on a worst case basis. The maximum weight and the distribution by axle per type was the same as used in the BRIGLD1 case. The distribution by type over the total truck population and the speed distribution within each type was also the same as was used in the BRIGLD1 case. However, the speed distribution is defined in a different manner in HISGEN, i.e., by specific speeds and the probability of each speed. The mid-points of each class interval defined in BRIGLD1 were chosen as the specific speeds and since there were ten class intervals, a probability of .1 was assigned to each speed.

Platoon definition was restricted to size 1 and 2 platoons with .80 and .20 probabilities respectively. This was based upon

1. The low incidence of multi-truck platoons generated in the traffic simulation,

2. The uncertainty about the validity of the traffic simulated data,

3. No evidence of multi-truck platoons in the field collected data, and

4. Intuitive estimating that at least platoons of size 2 would occur. However, the 20% probability was probably too high and should have been closer to 1%.

The truck traffic load data used was based upon actual field samples but no long term growth or decay was used. This was primarily due to the desire to compare the stress range histograms generated by this approach with the field collected sample and the traffic simulation generated sample. Passing and trailing truck platoon formations were set at 10% and 90% respectively.

The results of this test were unverifiable because of the stipulation of platoons. Consequently, a second case was run using only single truck platoons with a 10% passing lane occupancy. This, again, was unverifiable but only transferred the stress maxima between beams. The results of both cases are shown in table 21. The incidence used for each class interval of stress range were the accumulated stress peaks for the nine sample points on five beams. Consequently, there is a multiplicity of stress peaks for a given live load. For the case with platoons of size 1, a total accumulation of 23.59671×10^7 maxima were accumulated over the nine sample points for a total of 1.9399750×10^7 truck loads. Using a very simplistic analysis, the 9 sample points averaged 2.6218562×10^7 significant stress maxima. This implies that significant stress maxima were distributed to an average of 1.35 beams per truck load.

Significant use, manipulation and evaluation of this methodology is required before any significant conclusions can be drawn. Applied utilization of this approach during the study was very small and insufficient to provide an adequate learning basis. Results from methods such as this are extremely dependent upon how a user applies them and how well he understands the approach. Futher, as more field data is collected and more learned about the statistics of platooning trucks and the configurations of the platoons, the use of this method will improve.

TABLE 21. Comparison of Measured, Simulated and Directly Calculated Stress Maxima (I-83 and Bunker Hill Road)

Stress (Psi)	0 / 200	200 / 400	400 / 600	600 / 800	800 / 1000	1000 / 1200	1200 / 1400	1400 / 1600	1600 / 1800	1800 / ∞
Measured (%) (On the Cover Plate Ends)	10.0	61.0	26.0	2.0	-	-	-	-	-	-
Measured (%) (Off the Cover Plate Ends)	-	7.6	24.2	29.4	18.0	10.5	3.3	3.4	1.7	1.7
Predicted (%) (9 Sample Points) BRIGLD1/BRGSTRS	1.7	8.2	21.2	15.2	16.0	13.0	10.0	9.5	3.5	1.7
Predicted (%) (9 Sample Points) SYNGEN/BRGSTRS/HISGEN Platoon Test	0.4	2.9	8.2	10.3	9.6	4.7	2.2	1.5	1.9	58.4
50 Year Incidence (9 Sample Points) Platoon Test	$.1517 \times 10^7$	1.0992×10^7	3.1176×10^7	3.8980×10^7	3.6367×10^7	1.7833×10^7	$.8454 \times 10^7$	$.5852 \times 10^7$	$.71526 \times 10^7$	22.1891×10^7
Predicted (%) (9 Sample Points) SYNGEN/BRGSTRS/HISGEN Single Truck Test	3.2	16.2	21.5	32.2	18.6	6.4	2.2	2.6	2.9	3.1
50 Year Incidence (9 Sample Points) Single Truck Test	$.7677 \times 10^7$	3.828×10^7	5.0741×10^7	5.4685×10^7	4.3888×10^7	1.5156×10^7	$.53006 \times 10^7$	$.6102 \times 10^7$	$.6129 \times 10^7$	$.7301 \times 10^7$

GENERATED HISTOGRAMS AND RESULTS

As a result of the review of a suggested set of criteria for the bridges to be used for generating stress histograms, a candidate set of bridges were defined. The suggested criteria were

1. Composite deck, reinforced concrete, with steel main girders (wide flange).

2. Concrete deck with box main beams.

3. Reinforced concrete deck with concrete main girders.

4. Three cases to be run with a simple span configuration.

5. One case to be run with a 3 span continuous beam (.8L-L-.8L).

6. One case to be run with a 5 span continuous beam (.8L-L-L-L-.8L).

The identified candidate bridges, which were assumed to have adequate data available were

1. One simple span on Md. 301.
2. One simple span in Virginia.
3. The Dumfries bridge.
4. A continuous beam in Virginia.
5. A continuous beam in Md.
6. A continuous beam in Connecticut.
7. A continuous beam in Minnesota.

The bridges, and their related parameters, that were finally chosen on the basis of acquiring adequate data, within time and project constraints, were

1. I simple span of a two span, both identical, bridge at U.S. 301 and Md. Rt. 5, fabricated of steel beams and reinforced concrete deck.

2. The north span of a bridge at U.S. 301 at Western Branch in Maryland. This is a continuous beam of three spans.

3. The fifth span of a 5 span simply supported bridge at I-495 and U.S. 1 in Maryland.

4. The center span of a 3 span simply supported bridge, southbound on I-83 at Bunker Hill Road in Maryland.

5. The northern span of the simply supported bridge on I-95 at Dumfries, Virginia.

Upon detailed investigation of the "U.S. 301" data originally furnished in BRIGLD1, as contained data, it was determined that the truck incidence was approximately a factor of twenty time that collected in actual samples for the two bridges on U.S. 301 used in this project. In general it was found that this data was unrealistic and totally dependent upon the "Headway" data used.

Additionally, the truck data contained in this same source data was also unuseable. Consequently, each of the five bridges evaluated required a completely new set of traffic data, as opposed to the requirements of the contract for this project. The resulting load simulations evidenced a far greater time compression, approximately 720 to 1, of real time than was evidenced during the sensitivity testing. This was almost totally due to the change in traffic distribution data.

The truck weight and length data contained in the original BRIGLD1 program was modified to conform to more recent findings (2).

The simulation period, for the purposes of this project, was selected at five hours. This was predicated on the indications resulting from the Sensitivity Analysis.

No arbitrary platoon distribution was imposed on the simulations.

The procedure followed in producing the stress range incidence data was

1. Development of the necessary truck traffic distribution data and other required input data for the load simulation program, BRIGLD1 for each bridge to be analyzed.

2. Preparation of the data for input to the computer and running of the load simulation program on the computer for each bridge. A separate magnetic tape was utilized for the generated load data for each bridge.

3. Analyzing the results of the generated load data against the available real load data on each bridge.

4. Development of the structural input data for each bridge to be analyzed as required by the dynamic structural analysis program, BRGSTRS.

5. Preparation of card input data for each bridge, for BRGSTRS, and running each case on the computer using BRGSTRS, the card input data and the bridge corresponding load data generated by BRIGLD1 on magnetic tape.

6. Analyzing the generated stress range data against the available stress range data on each bridge.

The following subsections describe the data used for each bridge and the results obtained, in comparison with available real field data.

U.S. 301 and Md. Rt. 5

Auto traffic was assumed to be an arbitrary constant and set at 83% of the total traffic for this bridge. The truck distribution data used was based upon actual measurements taken at the bridge (3). This data only allowed for five truck types, i.e., 2D, 3, 2S1, 2S2 and 3S2. A comparison of the measured incidence of these truck types and the five hours of simulation generated by BRIGLD1 is shown in Table 22.

In this case no means of comparing total or average truck weights directly was possible from available data.

The manner in which the truck traffic appeared on the bridge deck in the simulation generated 84 load units of 84 single truck events in the five hours of simulated loading. The real sample contained 5284 trucks in a 7 day period or one truck every 1.91 minutes. The simulated sample contained approximately 1/2 of the truck traffic actually measured. This implies that the headway distribution data used in BRIGLD1 was skewed to the low side. This is possible since it was generated from 2 and 4 hour averages provided by the real data. The high frequency or short interval data was masked by the longer term means. This variance could have been corrected in BRIGLD1 by adjusting the headway tables to provide for the proper mean rate.

The input data used to generate this loading data is shown in Figure 6 as is the five hour generated data. A magnetic tape containing the synthetically generated time dependent load data, was produced simultaneously for input to the dynamic bridge stress analysis program (BRGSTRS).

TABLE 22. Comparison of Truck Distributions for the U.S. 301 and Md. Rt. 5 Bridge

Truck Types	2D	3	2S1	2S2	3S2
Measured (%)	22.5	5.7	8.5	20.0	43.3
Simulated (%)	22.6	5.9	5.9	22.6	42.9

Card input data was prepared from available information on the bridge, in particular the south span, and where data was insufficient , standard interstate bridge data was utilized.

```
&DATA
NTH=         1,TIMLIM=  18000.000     ,DELTIM=  1.0000000     ,MD=          6,NL=          2,ND=          1,PRAND=     654178,IOUT=
        7,BRLEN=  40.000000     ,BRPOS=  1040.0000     ,NZ=          0,SPDLIM=  95.333481     ,TRKLIM=  80.666794     ,EXSPD=
  22.000031     ,SPDMIN=  58.666763     ,ACCEL=  15.000000     ,SDFAC=  15.000000     ,SAFDIS=  10.000000     ,LT=          12,TALIMC=
  8000.0000     ,DBUG=F
&END
```

Figure 6. BRIGLD1 Output for U.S. 301 and Rt. 5

ZONE DATA

BEGIN FORWARD UPGRADE	END FORWARD UPGRADE	BEGIN REVERSE UPGRADE	END REVERSE UPGRADE	PERCENT OF GRADE
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0

VEHICLE DATA

VEHICLE TYPE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
NUMBER OF AXLES	2	2	2	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VEHICLE POWER	150.	136.	157.	165.	184.	184.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
VEHICLE LENGTH	19.0	23.0	28.0	54.0	54.0	54.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FIRST AXLE POSITION	3.0	4.0	4.0	4.0	4.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.50	.25	.25	.20	.10	.20	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
SECOND AXLE POSITION	14.0	19.0	20.0	15.5	15.5	17.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.50	.75	.75	.50	.30	.40	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
THIRD AXLE POSITION	0.0	0.0	0.0	48.0	48.0	48.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.0	.0	.0	.30	.60	.40	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
FOURTH AXLE POSITION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
FIFTH AXLE POSITION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

Figure 6. BRIGLD1 Output for U.S. 301 and Rt. 5 (Continued)

COEFFICIENTS OF ACCELERATION

WEIGHT/HORSEPOWER	C(0) +	C(1)V +	C(2)V**2 +	C(3)TAN(THETA)
0-50	14.70000	0.10000	0.0	140.00000
50-100	11.70000	0.09000	0.0	120.00000
100-200	13.00000	0.24700	0.00118	90.00000
200-300	9.30000	0.19600	0.00107	44.00000
300-400	5.70000	0.15000	0.00100	28.00000
OVER 400	4.00000	0.10200	0.00065	38.00000

Figure 6. BRIGLD1 Output for U.S. 301 and Rt. 5 (Continued)

A SIMULATION TO REPRESENT A PERIOD OF 5.0 HOURS.

VEHICLES ARE GENERATED 1040. FEET FROM BRIDGE-CENTER. WEIGHTS ON BRIDGE
ARE SUMMED AND COUNTED FOR LOAD INCREMENTS OF 8000. POUNDS UP TO 88000..
1 PERIOD TYPES AND 6 VEHICLES TYPES ARE CONSIDERED.

HEADWAY TABLES

VALUE NUMBER / DIRECTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	6.00	8.00	10.00	11.00	12.00	12.50	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00	20.50	21.00	22.00	23.00	24.00	25.00
2	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.30	1.50	1.60	1.80	2.00	2.10	2.50	2.80	3.00	3.50	4.10	5.20

VALUE NUMBER / DIRECTION	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	26.00	27.00	28.00	29.00	30.00	40.00	50.00	55.00	60.00	80.00	90.00	*****	*****	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	5.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SPEED TABLES

VEHICLE TYPE / VALUE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	40.	40.	30.	32.	32.	32.	32.	32.	32.	32.	32.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	66.	62.	56.	60.	60.	60.	60.	60.	60.	60.	60.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3	71.	66.	60.	66.	66.	66.	66.	66.	66.	66.	66.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4	74.	69.	64.	70.	70.	70.	70.	70.	70.	70.	70.	0.	0.	0.	0.	0.	0.	0.	0.	0.
5	77.	71.	67.	73.	73.	73.	73.	73.	73.	73.	73.	0.	0.	0.	0.	0.	0.	0.	0.	0.
6	80.	74.	70.	76.	76.	76.	76.	76.	76.	76.	76.	0.	0.	0.	0.	0.	0.	0.	0.	0.
7	83.	76.	72.	79.	79.	79.	79.	79.	79.	79.	79.	0.	0.	0.	0.	0.	0.	0.	0.	0.
8	86.	78.	75.	82.	82.	82.	82.	82.	82.	82.	82.	0.	0.	0.	0.	0.	0.	0.	0.	0.
9	89.	81.	78.	86.	86.	86.	86.	86.	86.	86.	86.	0.	0.	0.	0.	0.	0.	0.	0.	0.
10	94.	85.	83.	91.	91.	91.	91.	91.	91.	91.	91.	0.	0.	0.	0.	0.	0.	0.	0.	0.
11	120.	107.	109.	120.	120.	120.	120.	120.	120.	120.	120.	0.	0.	0.	0.	0.	0.	0.	0.	0.
12	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
13	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
14	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
15	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
17	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
18	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
19	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
20	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

WEIGHT TABLES

VEHICLE TYPE / VALUE	1	2	3	4	5	6	7	[illegible]	9	10	11	12
1	3000.	3000.	12000.	12000.	15000.	21000.	15000.	15000.	15000.	21000.	21000.	0.
2	3000.	6500.	16000.	16900.	19800.	23000.	19800.	19800.	19800.	23000.	23000.	0.
3	0.	7300.	17600.	18500.	21300.	25000.	21300.	21300.	21300.	25000.	25000.	0.
4	0.	8000.	19200.	19400.	22700.	26000.	22700.	22700.	22700.	26000.	26000.	0.
5	0.	8700.	20900.	20000.	24000.	27000.	24000.	24000.	24000.	27000.	27000.	0.

Figure 6. BRIGLD1 Output for U.S. 301 and Rt. 5 (Continued)

6	0.	9800.	22600.	20200.	25800.	29500.	25800.	25800.	25800.	29500.	29500.	0.
7	0.	10000.	25050.	21500.	28500.	34700.	28500.	28500.	28500.	34700.	34700.	0.
8	0.	10400.	27500.	22400.	32000.	45200.	32000.	32000.	32000.	45200.	45200.	0.
9	0.	11000.	29750.	23400.	34400.	52000.	34400.	34400.	34400.	52000.	52000.	0.
10	0.	11800.	32000.	24800.	36700.	56800.	36700.	36700.	36700.	56800.	56800.	0.
11	0.	12500.	33250.	26800.	38900.	60000.	38900.	38900.	38900.	60000.	60000.	0.
12	0.	13400.	34500.	29300.	41700.	62700.	41700.	41700.	41700.	62700.	62700.	0.
13	0.	14500.	35300.	30800.	44600.	65000.	44600.	44600.	44600.	65000.	65000.	0.
14	0.	16000.	36100.	31600.	47100.	66300.	47100.	47100.	47100.	66300.	66300.	0.
15	0.	17800.	37050.	32300.	48800.	67300.	48800.	48800.	48800.	67300.	67300.	0.
16	0.	18800.	38000.	33300.	52600.	68200.	52600.	52600.	52600.	68200.	68200.	0.
17	0.	19800.	39550.	34100.	55000.	69700.	55000.	55000.	55000.	69700.	69700.	0.
18	0.	20800.	41100.	35300.	57000.	70200.	57000.	57000.	57000.	70200.	70200.	0.
19	0.	21300.	46650.	37000.	58800.	71000.	58800.	58800.	58800.	71000.	71000.	0.
20	0.	22600.	52200.	39600.	61000.	71500.	61000.	61000.	61000.	71500.	71500.	0.
21	0.	25000.	55150.	59700.	65900.	83900.	65900.	65900.	65900.	83900.	83900.	0.
22	0.	0.	58100.	0.	0.	0.	0.	0.	0.	0.	0.	0.
23	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
24	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
25	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
26	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
27	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
28	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
29	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
30	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

TRAFFIC DISTRIBUTION

VEHICLE TYPE / DIRECTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.830	0.868	0.878	0.892	0.926	1.000	0.906	0.919	0.953	0.988	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	0.830	0.875	0.885	0.888	0.891	0.894	0.906	0.919	0.953	0.988	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

TRUCK PLATOON DISTRIBUTION

NUMBER OF TRUCKS / DIRECTION	1	2	3	4	5	6	7	8	9	10
1	1.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	1.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SIMULATION START AT 12.0 SECONDS, END AT START + 18000.0 SECONDS

BRIDGE LOAD TIME = 499.0000SEC

	LANE	WEIGHT	POSITION	DISTANCE	ACCELERATION	ORDER
1	1	17940.	-98.07	72.47	0.0	
2	1	17940.	-67.57	72.47	0.0	
3	1	8970.	-54.07	72.47	0.0	

EVENT NUMBER 1 NO. OF TRUCKS 1

TYPE WEIGHT SPEED LANE TIME ENTERING BRIDGE

Firuge 6. BRIGLD1 Output for U.S. 301 and Rt. 5 (Continued)

TOTAL VEHICLES GENERATED = 547 SIMULATED TIME = 18000. SECONDS

PLATOON DISTRIBUTION

	1	2	3	4	5	6	7	8	9	10
GENERATED FORWARD	84	0	0	0	0	0	0	0	0	0
SAMPLED ON BRIDGE	84	0	0	0	0	0	0	0	0	0

TYPE DISTRIBUTION

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
463	19	5	5	19	36	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LOAD DISTRIBUTION

0. TO 8000.	6
8000. TO 16000.	3
16000. TO 24000.	19
24000. TO 32000.	10
32000. TO 40000.	9
40000. TO 48000.	6
48000. TO 56000.	5
56000. TO 64000.	6
64000. TO 72000.	17
72000. TO 80000.	1
80000. TO 88000.	2
88000. TO 96000.	0
ABOVE 96000.	0

Figure 6. BRIGLD1 Output for U.S. 301 and Rt. 5 (Continued)

This particular case was the first production run attempted on BRGSTRS and there were the usual difficulties in learning how to use a newly constructed program and debugging the input data. The data interface from BRIGLD1 worked perfectly. However, it was a well planned move to limit the simulation period to five hours. The dynamic stress analysis program required 45 minutes of CPU time (360/65) in the "go" step. This implies a 6.67 to 1 compression of real time by the structural analysis program. However, this is a direct function of truck density and cannot be relied upon as a rule. This case, as indicated earlier, simulated 84 single trucks in the five hour period or one truck every 3.57 minutes. This span was also a simple span which did not require repetitive inversion of the modified flexibility matrix.

The gross results of the generated stress data for the simulated truck traffic over the five hour period is shown in comparison with field measured data on this span in Table 23.

The results compare very favorably with the data measured at the center span position on the cover plate. This was for the 3rd beam in both cases. The input data defined a cover plate on the beam and the resultant calculations should correlate with the cover plate data. The variances in the 400 - 600 and 800 - 1000 class intervals are apparently due to a variance in the weights of the trucks of the same types between the real and the simulated. As indicated earlier, there was no direct means of correlating the weights of the trucks within a given type. The traffic simulator program, BRIGLD1, appears to have generated heavier trucks, by type, than the real sample. This tendency was verified in the fifth test case, the Dumfries, Virginia, bridge, which is described later. The truck weight distribution data utilized was based upon a generalized data covering several of the mid-Atlantic states (2). The local utilization of these truck types in the area

surrounding this bridge may be toward lighter loading than that found in the total mid-Atlantic region.

The input data used to describe the structual characteristics of this bridge for BRGSTRS is shown in Figure 7. A sample of the stresses calculated are also shown in Figure 7 as is an example of the graphical output. The scaling on the graphical output was changed in the later cases to one half that used in this case. The histogram generated for this case is also shown in Figure 7. As can be seen, the selection of the class interval size and maximum range was poorly defined in the input data to the program. This input was modified in the other cases.

TABLE 23. Comparison of Measured and Predicted Incidence of Bridge Stess Maxima
(U.S. 301 and Md. Rt. 5)

Stress (PSI)	0 / 200	200 / 400	400 / 600	600 / 800	800 / 1000	1000 / 1200	1200 / 1400	1400 / 1600	1600 / 1800	1800 / 2000	2000 / 2200	2200 / 2400	2400 / ∞
Measured (%) on Cover Plate (611 Trucks)	0.15	14.50	30.00	32.00	19.00	10.50	3.40	0.55	0.00	0.00	0.00	0.00	0.00
*Predicted (%) (84 Trucks)	0.00	13.30	20.00	23.00	36.70	5.00	1.70	0.00	0.00	0.00	0.00	0.00	0.00
Measured (%) Off Cover Plate (611 Trucks)	0.00	3.05	13.10	19.75	18.00	12.50	11.75	11.85	5.75	3.00	0.00	0.00	0.00

*Calculations assumed Cover Plate.

```
    MD 301 AND RT 5 - SIMPLE SPAN STEEL BEAM

 INPUT TAPE NO.   7    OUTPUT TAPE NO.    0
 &INPUTA
 XLE=  76.832993    ,NL=             2,YBCL=  19.079987    ,EC=  4300000.0    ,ES=  30000000.    ,NUC= 0.19999999    ,NUS=
  0.29999995    ,DT= 0.49999997E-01,THRSH=  20.000000    ,WEIGHT=  303000.00    ,DR= 0.62500000    ,NUS= 0.29999995    ,CRUD=
  1.0000000    ,CRLD=  6.0000000    ,NB=            8,NSUF=            2,C2LRU= 0.0            ,C2LRL= 0.0            ,DRT=
  0.87500000    ,NLRU=            5,NLRL=            4,CLRU=  5.5000000    ,CLRL=  1.5000000    ,ILSC=            0,T1=  7.0000000    ,IL=
            1,SIGTHS=  300.00000    ,DSIG=  1000.0000    ,NDBUG=            0,            0,            0,            0,            0,
          0,            0,            0,            0,            0
 &END
```

Figure 7. BRGSTRS Output for U.S. 301 and Rt. 5

```
YCL(J)
        11.5800          26.5800

SUPPORT POSITIONS        0.0        76.83

 BEAM   NRU   NRL        IUR          ILR          YB          B     NCS   ISC    IB
   1     2     5     0.749E-05    0.749E-05      0.375       3.330    3     1      1
 XCS(N,J)
     19.151      57.453      76.604
 INRT,EBAR,C,E
     0.307E 05      0.300E 08      17.800      0.300E 08
 INRT,EBAR,C,E
     0.307E 05      0.300E 08      17.800      0.300E 08
 INRT,EBAR,C,E
     0.307E 05      0.300E 08      17.800      0.300E 08

 BEAM   NRU   NRL        IUR          ILR          YB          B     NCS   ISC    IB
   2     5    10     0.749E-05    0.749E-05      5.583       5.250    3     1      1
 XCS(N,J)
     19.151      57.453      76.604
 INRT,EBAR,C,E
     0.307E 05      0.300E 08      17.800      0.300E 08
 INRT,EBAR,C,E
     0.307E 05      0.300E 08      17.800      0.300E 08
 INRT,EBAR,C,E
     0.307E 05      0.300E 08      17.800      0.300E 08

 BEAM   NRU   NRL        IUR          ILR          YB          B     NCS   ISC    IB
   3     5    10     0.749E-05    0.749E-05     10.833       5.250    3     1      1
 XCS(N,J)
     19.151      57.453      76.604
 INRT,EBAR,C,E
     0.307E 05      0.300E 08      17.800      0.300E 08
 INRT,EBAR,C,E
     0.307E 05      0.300E 08      17.800      0.300E 08
 INRT,EBAR,C,E
     0.307E 05      0.300E 08      17.800      0.300E 08

 BEAM   NRU   NRL        IUR          ILR          YB          B     NCS   ISC    IB
   4     5    10     0.749E-05    0.749E-05     16.083       5.250    3     1      1
 XCS(N,J)
     19.151      57.453      76.604
 INRT,EBAR,C,E
     0.307E 05      0.300E 08      17.800      0.300E 08
 INRT,EBAR,C,E
     0.307E 05      0.300E 08      17.800      0.300E 08
 INRT,EBAR,C,E
     0.307E 05      0.300E 08      17.800      0.300E 08

 BEAM   NRU   NRL        IUR          ILR          YB          B     NCS   ISC    IB
   5     5    10     0.749E-05    0.749E-05     21.333       5.250    3     1      1
 XCS(N,J)
     19.151      57.453      76.604
 INRT,EBAR,C,E
     0.307E 05      0.300E 08      17.800      0.300E 08
 INRT,EBAR,C,E
     0.307E 05      0.300E 08      17.800      0.300E 08
 INRT,EBAR,C,E
     0.307E 05      0.300E 08      17.800      0.300E 08

 BEAM   NRU   NRL        IUR          ILR          YB          B     NCS   ISC    IB
```

Figure 7. BRGSTRS Output for U.S. 301 and Rt. 5 (Continued)

```
      6    5   10     0.749E-05      0.749E-05     26.583       5.250    3     1     1
   XCS(N,J)
        19.151      57.453      76.604
   INRT,EBAR,C,E
            0.307E 05       0.300E 08       17.800        0.300E 08
   INRT,EBAR,C,E
            0.307E 05       0.300E 08       17.800        0.300E 08
   INRT,EBAR,C,E
            0.307E 05       0.300E 08       17.800        0.300E 08

    BEAM   NRU   NRL            IUR            ILR            YB           B    NCS    ISC     IB
      7     5    10     0.749E-05      0.749E-05     31.833       5.250    3     1     1
   XCS(N,J)
        19.151      57.453      76.604
   INRT,EBAR,C,E
            0.307E 05       0.300E 08       17.800        0.300E 08
   INRT,EBAR,C,E
            0.307E 05       0.300E 08       17.800        0.300E 08
   INRT,EBAR,C,E
            0.307E 05       0.300E 08       17.800        0.300E 08

    BEAM   NRU   NRL            IUR            ILR            YB           B    NCS    ISC     IB
      8     2     5     0.749E-05      0.749E-05     37.041       3.330    3     1     1
   XCS(N,J)
        19.151      57.453      76.604
   INRT,EBAR,C,E
            0.307E 05       0.300E 08       17.800        0.300E 08
   INRT,EBAR,C,E
            0.307E 05       0.300E 08       17.800        0.300E 08
   INRT,EBAR,C,E
            0.307E 05       0.300E 08       17.800        0.300E 08

          CELX            IT            ET
          7.670     0.103E 05     0.300E 07

   ICPT1  ICPT2  IOPT3  IOPT4
      1      1      1      0

   NPTS    POINT 1    POINT 2    POINT 3    INPUT  POINTS

      0       0.0
      0       0.0
      1      38.302
      1      38.302
      1      38.302
      2      19.151      38.302
      0       0.0
      0       0.0

    GRID CENTERS LONGITUDINALLY - X
     0.3835E 01  0.1150E 02  0.1917E 02  0.2684E 02  0.3451E 02  0.4218E 02  0.4985E 02  0.5752E 02  0.6519E 02  0.7286E 02
     0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
     0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
     0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
     0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
     0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
     0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
     0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0

   NPTS    POINT 1    POINT 2    POINT 3    CONVERTED POINTS
```

Figure 7. BRGSTRS Output for U.S. 301 and Rt. 5 (Continued)

```
      0      0.0
      0      0.0
      1     34.515
      1     34.515
      1     34.515
      2     15.175     34.515
      0      0.0
      0      0.0
   IPTS
      0   0   0      0   0   0      5   0   0      5   0   0      5   0   0
      3   5   0      0   0   0      0   0   0      0   0   0      0   0   0
```

Figure 7. BRGSTRS Output for U.S. 301 and Rt. 5 (Continued)

STRESS EVENT 22 LOAD EVENT 38 BEAM 3 PCINTS * 3+.515

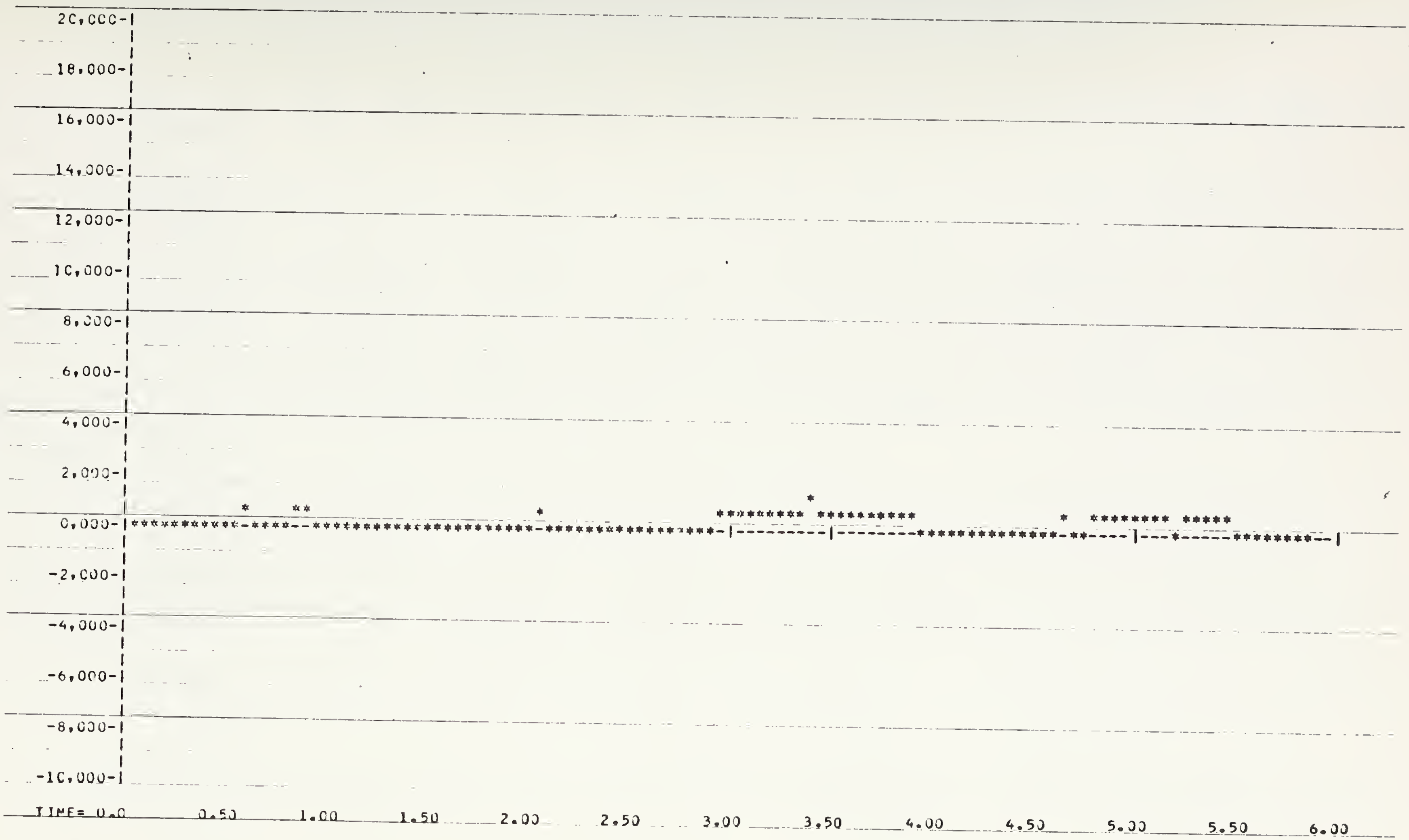


Figure 7. BRGSTRS Output for U.S. 301 and Rt. 5 (Continued)

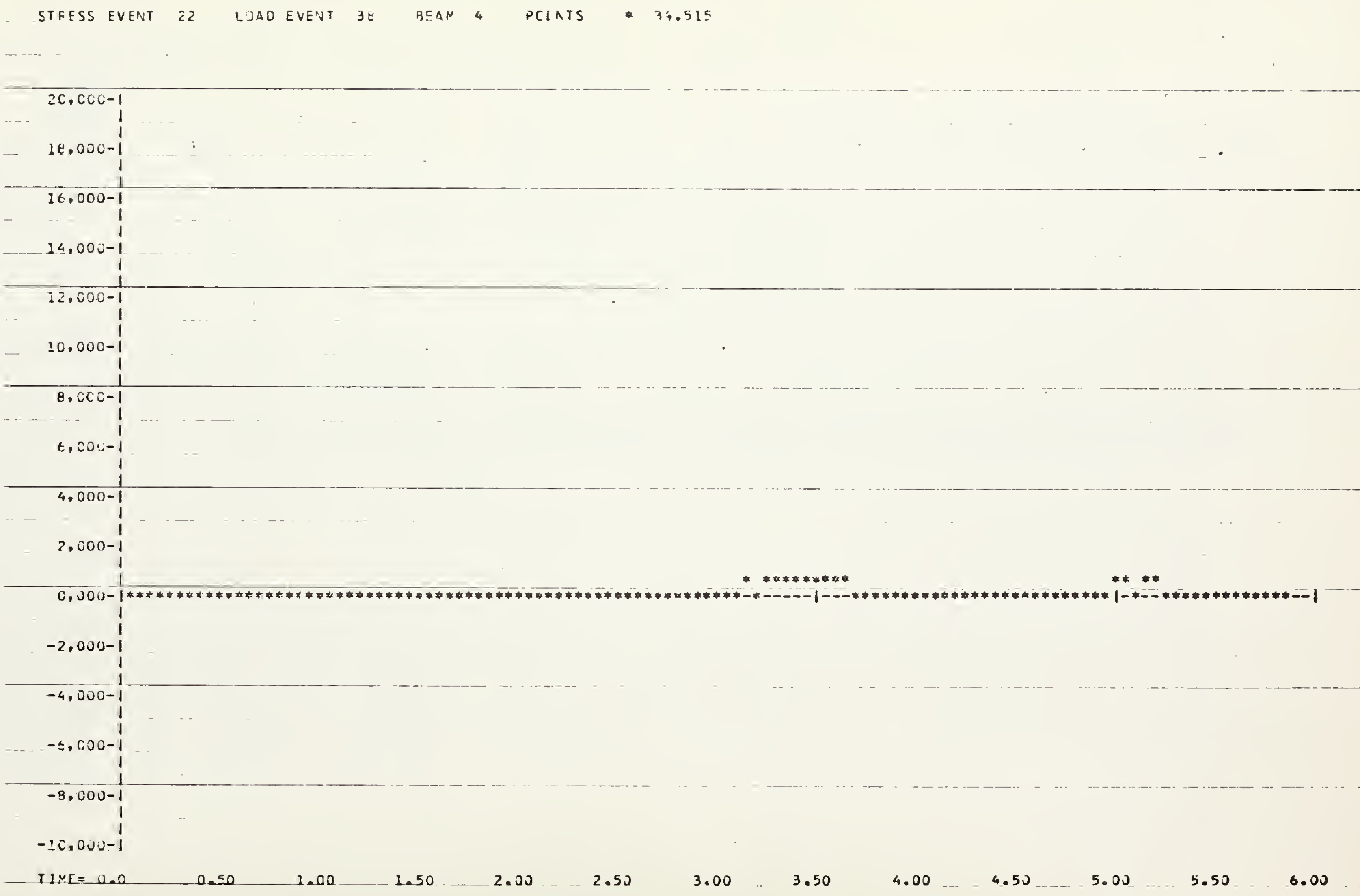


Figure 7. BRGSTRS Output for U.S. 301 and Rt. 5 (Continued)

STRESS EVENT 22 LOAD EVENT 36 BEAM 5 POINTS * 34.515

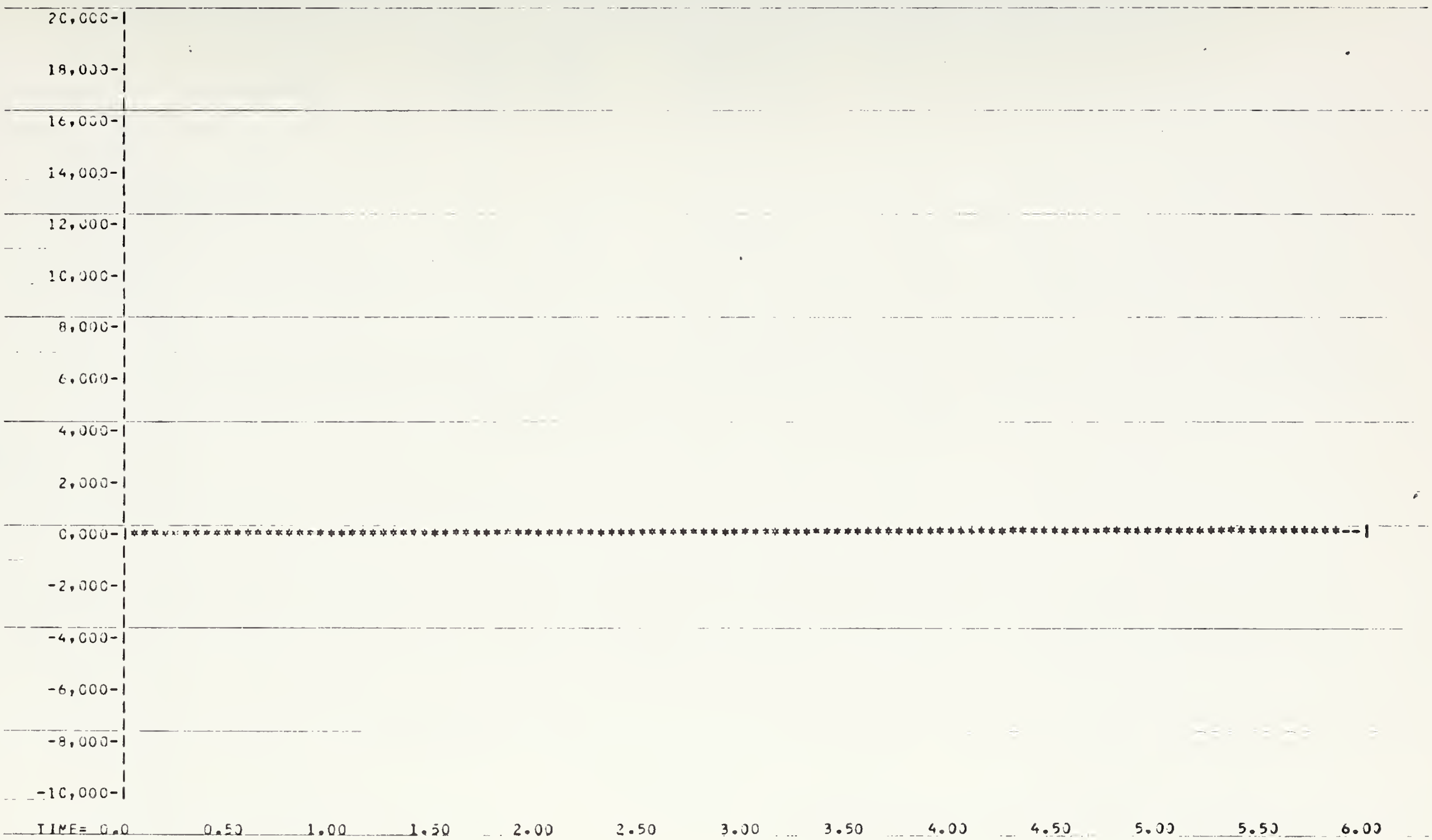


Figure 7. BRGSTRS Output for U.S. 301 and Rt. 5 (Continued)

STRESS EVENT 22 LOAD EVENT 38 BEAM 6 POINTS * 19.175 + 34.515

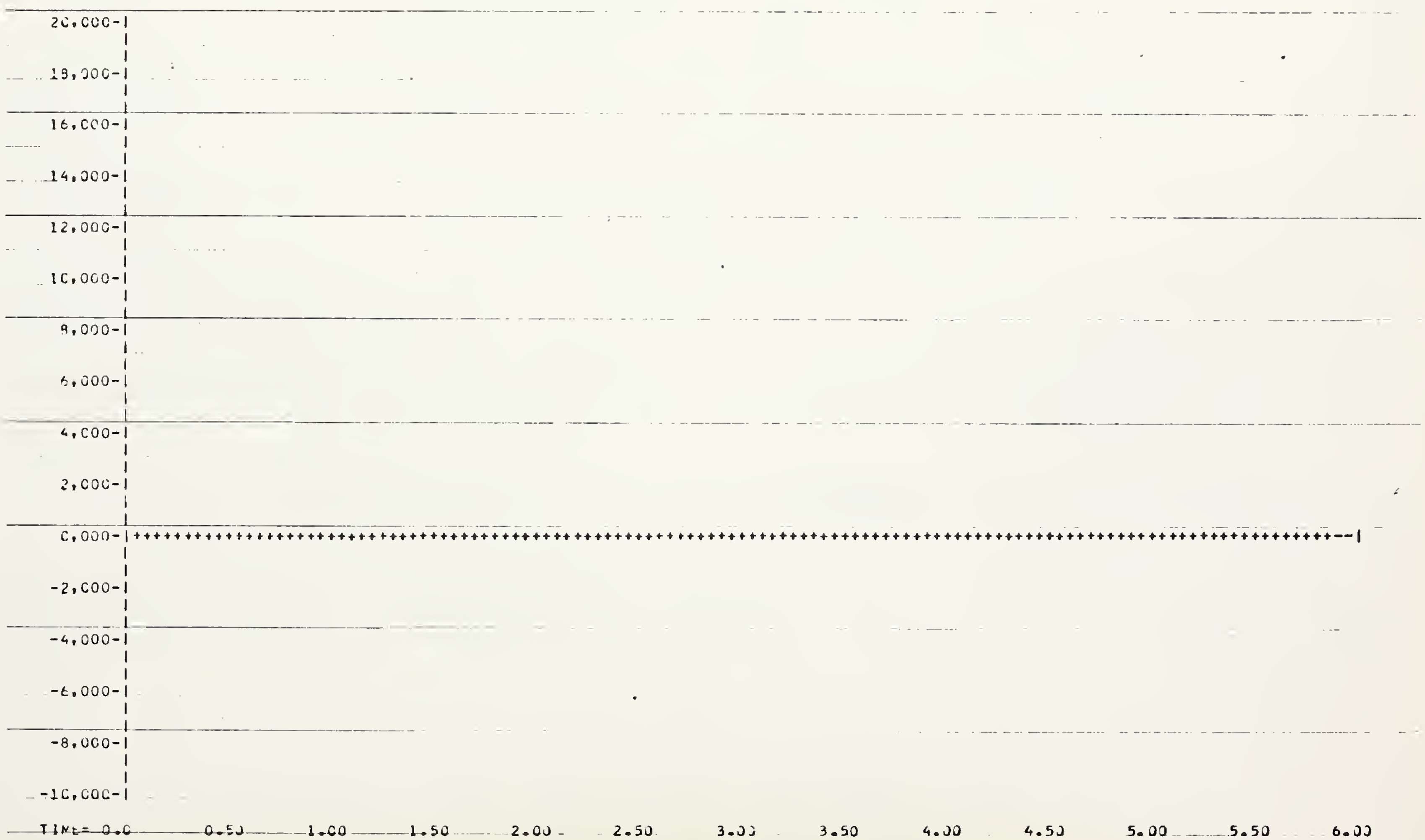


Figure 7. BRGSTRS Output for U.S. 301 and Rt. 5 (Continued)

```
STRESS EVENT  22    LOAD EVENT  38

BEAM NO.   3    POINT    34.515

STRESSES: MINIMUM   TIME           MAXIMUM   TIME          RANGE
             6.09   0.050           379.28   0.850         373.19
             3.70   1.350          1003.60   3.400         999.90
             7.57   4.200           760.50   5.050         752.94
           330.28   5.200           640.90   5.300         310.62

BEAM NO.   4    POINT    34.515

STRESSES: MINIMUM   TIME           MAXIMUM   TIME          RANGE

BEAM NO.   5    POINT    34.515

STRESSES: MINIMUM   TIME           MAXIMUM   TIME          RANGE

BEAM NO.   6    POINT    19.175

STRESSES: MINIMUM   TIME           MAXIMUM   TIME          RANGE

BEAM NO.   6    POINT    34.515

STRESSES: MINIMUM   TIME           MAXIMUM   TIME          RANGE
```

Figure 7. BRGSTRS Output for U.S. 301 and Rt. 5 (Continued)

STRESS HISTOGRAMS

10% INTERVALS TO 1000.0 TO 2000.0 TO 3000.0 TO 4000.0 TO 5000.0 TO 6000.0 TO 7000.0 TO 8000.0 TO 9000.0 TO 10000.0

BEAM	POINT										
1	**********	******	******	******	0	0	0	0	0	0	******
2	**********	******	******	******	******	******	******	******	******	******	******
3	34.515	56	4	0	0	0	0	0	0	0	0
4	34.515	13	0	0	0	0	0	0	0	0	0
5	34.515	0	0	0	0	0	0	0	0	0	0
9	19.175	0	0	0	0	0	0	0	0	0	0
6	34.515	0	0	0	0	0	0	0	0	0	0
7	0.0	0	0	0	0	0	0	0	0	0	0
8	0.0	0	0	0	0	0	0	0	0	0	0

Figure 7. BRGSTRS Output for U.S. 301 and Rt. 5 (Continued)

U.S. 301 and Western Branch

Auto traffic was assumed to be an arbitrary constant and set at 83% of the total traffic for this bridge. The truck distribution data used was based upon actual measurements taken at the bridge (4). This data only allowed for five truck types, i.e., 2D, 3, 2S1, 2S2 and 3S2. A comparison of the measured incidence of these truck types and the five hours of simulation generated by BRIGLD1 is shown in Table 24.

In this case no means of comparing total or average truck weights directly was possible from available data.

The manner in which the truck traffic appeared on the bridge deck in the simulation generated 65 load events of 65 single truck events in the five hours of simulated loading. The output from BRIGLD1 of this data is shown in Figure 8.

Table 24. Comparison of Truck Distribution for the U.S. 301/ Western Branch Bridge

Truck Types	2D	3	2S1	2S2	3S2
Measured (%)	27.0	6.0	5.0	21.0	41.0
Simulated (%)	30.8	4.6	0.0	20.0	44.6

```
&DATA
NTH=          1,TIMLIM=  18000.000     ,DELTIM=  1.0000000     ,MD=            6,NL=            2,ND=            1,MRAND=      51784,IOUT=
     7,BRLEN=  70.000000     ,BRPOS=  1070.0000     ,NZ=             0,SPDLIM=  95.333481     ,TRKLIM=  80.666794     ,EXSPD=
 22.000031     ,SPDMIN=  58.666763     ,ACCEL=  15.000000     ,SDFAC=  15.000000     ,SAFDIS=  10.000000     ,LT=           12,TALINC=
 8000.0000     ,DBUG=F
&END
```

Figure 8. BRIGLD1 Output for U.S. 301 and Western Branch

ZONE DATA

BEGIN FORWARD UPGRADE	END FORWARD UPGRADE	BEGIN REVERSE UPGRADE	END REVERSE UPGRADE	PERCENT OF GRADE
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0

VEHICLE DATA

VEHICLE TYPE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
NUMBER OF AXLES	2	2	2	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VEHICLE POWER	150.	136.	157.	165.	184.	184.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
VEHICLE LENGTH	19.0	23.0	28.0	54.0	54.0	54.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FIRST AXLE POSITION	3.0	4.0	4.0	4.0	4.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.50	.25	.25	.20	.10	.20	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
SECOND AXLE POSITION	14.0	19.0	20.0	15.5	15.5	17.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.50	.75	.75	.50	.30	.40	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
THIRD AXLE POSITION	0.0	0.0	0.0	48.0	48.0	48.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.0	.0	.0	.30	.60	.40	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
FOURTH AXLE POSITION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
FIFTH AXLE POSITION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

Figure 8. BRIGLD1 Output for U.S. 301 and Western Branch (Continued)

COEFFICIENTS OF ACCELERATION

WEIGHT/HORSEPOWER	C(0) +	C(1)V +	C(2)V**2 +	C(3)TAN(THETA)
0-50	14.70000	0.10000	0.0	140.00000
50-100	11.70000	0.09000	0.0	120.00000
100-200	13.00000	0.24700	0.00118	90.00000
200-300	9.30000	0.19800	0.00107	44.00000
300-400	5.70000	0.15000	0.00100	28.00000
OVER 400	4.00000	0.10200	0.00065	38.00000

Figure 8. BRIGLD1 Output for U.S. 301 and Western Branch (Continued)

A SIMULATION TO REPRESENT A PERIOD OF 5.0 HOURS.

VEHICLES ARE GENERATED 1070. FEET FROM BRIDGE-CENTER. WEIGHTS ON BRIDGE
ARE SUMMED AND COUNTED FOR LOAD INCREMENTS OF 8000. POUNDS UP TO 88000..
1 PERIOD TYPES AND 6 VEHICLES TYPES ARE CONSIDERED.

HEADWAY TABLES

VALUE NUMBER / DIRECTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	12.00	16.00	18.00	19.00	20.00	21.00	22.00	23.00	24.00	25.00	26.00	27.00	28.00	29.00	30.00	35.00	40.00	45.00	50.00	60.00
2	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.30	1.50	1.60	1.80	2.00	2.10	2.50	2.80	3.00	3.50	4.10	5.20

VALUE NUMBER / DIRECTION	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	70.00	80.00	90.00	*****	*****	*****	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	5.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SPEED TABLES

VEHICLE TYPE / VALUE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	40.	40.	30.	32.	32.	32.	32.	32.	32.	32.	32.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	66.	62.	56.	60.	60.	60.	60.	60.	60.	60.	60.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3	71.	66.	60.	66.	66.	66.	66.	66.	66.	66.	66.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4	74.	69.	64.	70.	70.	70.	70.	70.	70.	70.	70.	0.	0.	0.	0.	0.	0.	0.	0.	0.
5	77.	71.	67.	73.	73.	73.	73.	73.	73.	73.	73.	0.	0.	0.	0.	0.	0.	0.	0.	0.
6	80.	74.	70.	76.	76.	76.	76.	76.	76.	76.	76.	0.	0.	0.	0.	0.	0.	0.	0.	0.
7	83.	76.	72.	79.	79.	79.	79.	79.	79.	79.	79.	0.	0.	0.	0.	0.	0.	0.	0.	0.
8	86.	78.	75.	82.	82.	82.	82.	82.	82.	82.	82.	0.	0.	0.	0.	0.	0.	0.	0.	0.
9	89.	81.	78.	86.	86.	86.	86.	86.	86.	86.	86.	0.	0.	0.	0.	0.	0.	0.	0.	0.
10	94.	85.	83.	91.	91.	91.	91.	91.	91.	91.	91.	0.	0.	0.	0.	0.	0.	0.	0.	0.
11	120.	107.	109.	120.	120.	120.	120.	120.	120.	120.	120.	0.	0.	0.	0.	0.	0.	0.	0.	0.
12	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
13	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
14	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
15	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
17	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
18	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
19	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
20	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

WEIGHT TABLES

VEHICLE TYPE / VALUE	1	2	3	4	5	6	7	8	9	10	11	12
1	3000.	3000.	12000.	12000.	15000.	21000.	15000.	15000.	15000.	21000.	21000.	0.
2	3000.	6500.	16000.	16900.	19800.	23000.	19800.	19800.	19800.	23000.	23000.	0.
3	0.	7300.	17600.	18500.	21300.	25000.	21300.	21300.	21300.	25000.	25000.	0.
4	0.	8000.	19200.	19400.	22700.	26000.	22700.	22700.	22700.	26000.	26000.	0.
5	0.	8700.	20900.	20000.	24000.	27000.	24000.	24000.	24000.	27000.	27000.	0.

Figure 8. BRIGLD1 Output for U.S. 301 and Western Branch (Continued)

6	0.	9800.	22600.	20200.	25800.	29500.	25800.	25800.	25800.	29500.	29500.	0.
7	0.	10000.	25050.	21500.	28500.	34700.	28500.	28500.	28500.	34700.	34700.	0.
8	0.	10400.	27500.	22400.	32000.	45200.	32000.	32000.	32000.	45200.	45200.	0.
9	0.	11000.	29750.	23400.	34400.	52000.	34400.	34400.	34400.	52000.	52000.	0.
10	0.	11800.	32000.	24800.	36700.	56800.	36700.	36700.	36700.	56800.	56800.	0.
11	0.	12500.	33250.	26800.	38900.	60000.	38900.	38900.	38900.	60000.	60000.	0.
12	0.	13400.	34500.	29300.	41700.	62700.	41700.	41700.	41700.	62700.	62700.	0.
13	0.	14500.	35300.	30800.	44600.	65000.	44600.	44600.	44600.	65000.	65000.	0.
14	0.	16000.	36100.	31600.	47100.	66300.	47100.	47100.	47100.	66300.	66300.	0.
15	0.	17800.	37050.	32300.	48800.	67300.	48800.	48800.	48800.	67300.	67300.	0.
16	0.	18800.	38000.	33300.	52600.	68200.	52600.	52600.	52600.	68200.	68200.	0.
17	0.	19800.	39550.	34100.	55000.	69700.	55000.	55000.	55000.	69700.	69700.	0.
18	0.	20800.	41100.	35300.	57000.	70200.	57000.	57000.	57000.	70200.	70200.	0.
19	0.	21300.	46650.	37000.	58800.	71000.	58800.	58800.	58800.	71000.	71000.	0.
20	0.	22600.	52200.	39600.	61000.	71500.	61000.	61000.	61000.	71500.	71500.	0.
21	0.	25000.	55150.	59700.	65900.	83900.	65900.	65900.	65900.	83900.	83900.	0.
22	0.	0.	58100.	0.	0.	0.	0.	0.	0.	0.	0.	0.
23	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
24	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
25	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
26	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
27	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
28	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
29	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
30	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

TRAFFIC DISTRIBUTION

VEHICLE TYPE / DIRECTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.830	0.876	0.886	0.894	0.930	1.000	0.906	0.919	0.953	0.988	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	0.830	0.875	0.885	0.888	0.891	0.894	0.906	0.919	0.953	0.988	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

TRUCK PLATOON DISTRIBUTION

NUMBER OF TRUCKS / DIRECTION	1	2	3	4	5	6	7	8	9	10
1	1.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	1.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SIMULATION START AT 13.0 SECONDS, END AT START + 18000.0 SECONDS

Figure 8. BRIGLD1 Output for U.S. 301 and Western Branch (Continued)

TOTAL VEHICLES GENERATED = 401 SIMULATED TIME = 18000. SECONDS

PLATOON DISTRIBUTION

	1	2	3	4	5	6	7	8	9	10
GENERATED FORWARD	65	0	0	0	0	0	0	0	0	0
SAMPLED ON BRIDGE	65	0	0	0	0	0	0	0	0	0

TYPE DISTRIBUTION

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
336	20	3	0	13	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LOAD DISTRIBUTION

0. TO 8000.	1
8000. TO 16000.	8
16000. TO 24000.	16
24000. TO 32000.	10
32000. TO 40000.	6
40000. TO 48000.	2
48000. TO 56000.	3
56000. TO 64000.	10
64000. TO 72000.	6
72000. TO 80000.	1
80000. TO 88000.	2
88000. TO 96000.	0
ABOVE 96000.	0

Figure 8. BRIGLD1 Output for U.S. 301 and Western Branch (Continued)

As in the previous case, the truck traffic generated by BRIGLD1 was less than the real sample. However, in this case the real sample was taken over a period of four days in nominally 4 hour periods during daytime and may not be truly representative of long term behavior. The simulator generated at the rate of 13 trucks per hour while the real sample evidenced a rate of 20 per hour. This case actually came closer to generating the proper amount of truck traffic for the five hour simulation period than any of the other cases at 65% of the real sample's rate. This undergeneration is again due to the unavailability of the high frequency truck occurrence data which would have allowed development of a better set of headway input data. This can be easily adjusted by shifting the headway distribution function into the shorter time interval region.

In terms of the stress range portion of the analysis,of this bridge, this was the only continuous multi-span beam bridge tested on the program BRGSTRS. All of the other cases were of a simple span design.

The run with BRGSTRS was terminated due to excessive CP time. Eight load events were processed in 58 minutes of CP time. These eight load events were equivalent to approximately 40 minutes of simulated times. The extremely slow calculation of the stresses is due to the repetitive solution of the flexibility matrices and the inversion of their modified form. However, the calculated dynamic stresses provided 13 points of maxima from 4 specified sample points, i.e., one sample point on beams 2, 3, 4, and 5. It was decided that due to the extreme slowness of BRGSTRS in handling a continuous beam case that the results obtained from this one run would be used for comparative analyses with real data to provide some insight into the validity of the BRGSTRS output for continuous beams. This comparison

is shown in Table 25. The predicted data was based upon an extremely small sample. Further, the load data generated by BRIGLD1 during the first half hour of simulated time was skewed toward low truck weights. The heaviest truck generated during this period was in the 32,000 to 40,000 lb. range and it caused a maximum stress point of 2076 psi, or about 1/2 of the total measured stress range. Correlated with this is that the mean measured stress range was approximately 1750 psi while the predicted mean stress range was 820 psi, or about 1/2 the measured mean. The heavier trucks did not appear in the simulated load data until approximately 1-1/2 hours of simulation had occurred.

Hence, the predicted results, while small in guantity appear to relate well to the collected field data for lighter truck loadings.

I-495 and U.S. 1

Auto traffic was assumed to be an arbitrary constant and set at 83% of the total traffic for this bridge. The truck distribution data used was based upon actual measurements taken at the bridge (3). This data only allowed for five truck types, i.e., 2D, 3, 2S1, 2S2 and 3S2. A comparison of the measured incidence of these truck types and the five hours of simulation generated by BRIGLD1 is shown in Table 26.

In this case no means of comparing total or average truck weights directly was possible from available data.

TABLE 25. Comparison of Measured and Predicted Incidence of Bridge Stress Maxima (U.S. 301 and Western Branch)

Stress Range (PSI)	250 / 500	500 / 750	750 / 1000	1000 / 1250	1250 / 1500	1500 / 1750	1750 / 2000	2000 / 2250	2250 / 2500	2500 / 2750	2750 / 3000	3000 / 6000
Measured (%) (1195 Trucks)	1.5	5.0	8.0	11.0	11.0	10.5	9.5	9.0	9.0	8.0	5.0	12.5
Predicted (%) (8 Trucks)	23.1	30.8	23.1	15.4	-	-	-	7.7	-	-	-	-

TABLE 26. Comparison of Truck Distributions for the I-495/U.S. 1 Bridge

Truck Types	2D	3	2S1	2S2	3S2
Measured (%)	37.7	19.5	8.8	15.3	18.7
Simultated (%)	37.9	20.4	8.7	13.6	19.4

The manner in which the truck traffic appeared on the bridge deck in the simulation generated 102 load events of 101 single truck events and one two truck platoon, in the five hours of simulated loading.

This case also under generated truck traffic in comparison to the available real sample. The real sample acquired 637 trucks in a 14.5 hours of sampling. However, the simulated sample only produced 103 trucks in a five hour period, or only about 1/2 the rate indicated by the real data. Two factors must be considered in this instance, i.e.,

1. The low frequency data was not available from the real sample to generate the headway data for the simulation which was generated from 2 and 4 hour means.

2. The 14-1/2 hours of real sampling was heavily skewed to the high intensity period of the day, i.e., from 12:00 midnight to 2:30 p.m., and does not include the low intensity periods during a 24 hour cycle nor the weekly cycle.

The input data used to generate this loading data is shown in Figure 9 and the five hour generated data is shown in Figure 9.

```
&DATA
NTH=            1,TIMLIM=  18000.000     ,DELTIM=  1.0000000     ,MD=            6,NL=            2,ND=            1,NRAND=      651784,IOUT=,
        7,BRLEN=  20.000000     ,BRPOS=  1020.0000     ,NZ=             0,SPDLIM=  95.333481     ,TRKLIM=  80.666794     ,EXSPD=
  22.000031     ,SPDMIN=  58.666763     ,ACCEL=  15.000000     ,SDFAC=  15.000000     ,SAFDIS=  10.000000     ,LT=            12,TALINC=
  8000.0000     ,DBUG=F
&END
```

Figure 9. BRIGLD1 Output for I-495 and U.S.1

ZONE DATA

BEGIN FORWARD UPGRADE	END FORWARD UPGRADE	BEGIN REVERSE UPGRADE	END REVERSE UPGRADE	PERCENT OF GRADE
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0

VEHICLE DATA

VEHICLE TYPE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
NUMBER OF AXLES	2	2	2	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VEHICLE POWER	150.	136.	157.	165.	184.	184.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
VEHICLE LENGTH	19.0	23.0	28.0	54.0	54.0	54.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FIRST AXLE POSITION	3.0	4.0	4.0	4.0	4.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.50	.25	.25	.20	.10	.20	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
SECOND AXLE POSITION	14.0	19.0	20.0	15.5	15.5	17.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.50	.75	.75	.50	.30	.40	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
THIRD AXLE POSITION	0.0	0.0	0.0	48.0	48.0	48.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.0	.0	.0	.30	.60	.40	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
FOURTH AXLE POSITION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
FIFTH AXLE POSITION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

Figure 9. BRIGLD1 Output for I-495 and U.S.1 (Continued)

COEFFICIENTS OF ACCELERATION

WEIGHT/HORSEPOWER	C(0) +	C(1)V +	C(2)V**2 +	C(3)TAN(THETA)
0-50	14.70000	0.10000	0.0	140.00000
50-100	11.70000	0.09000	0.0	120.00000
100-200	13.00000	0.24700	0.00118	90.00000
200-300	9.30000	0.19800	0.00107	44.00000
300-400	5.70000	0.15000	0.00100	28.00000
OVER 400	4.00000	0.10200	0.00065	38.00000

Figure 9. BRIGLD1 Output for I-495 and U.S. 1 (Continued)

A SIMULATION TO REPRESENT A PERIOD OF 5.0 HOURS.

VEHICLES ARE GENERATED 1020. FEET FROM BRIDGE-CENTER. WEIGHTS ON BRIDGE
ARE SUMMED AND COUNTED FOR LOAD INCREMENTS OF 8000. POUNDS UP TO 88000..
1 PERIOD TYPES AND 6 VEHICLES TYPES ARE CONSIDERED.

HEADWAY TABLES

VALUE NUMBER / DIRECTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00	30.00	40.00	50.00
2	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.30	1.50	1.60	1.80	2.00	2.10	2.50	2.80	3.00	3.50	4.10	5.20

VALUE NUMBER / DIRECTION	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	60.00	80.00	*****	*****	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	5.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SPEED TABLES

VEHICLE TYPE / VALUE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	40.	40.	30.	32.	32.	32.	32.	32.	32.	32.	32.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	66.	62.	56.	60.	60.	60.	60.	60.	60.	60.	60.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3	71.	66.	60.	66.	66.	66.	66.	66.	66.	66.	66.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4	74.	69.	64.	70.	70.	70.	70.	70.	70.	70.	70.	0.	0.	0.	0.	0.	0.	0.	0.	0.
5	77.	71.	67.	73.	73.	73.	73.	73.	73.	73.	73.	0.	0.	0.	0.	0.	0.	0.	0.	0.
6	80.	74.	70.	76.	76.	76.	76.	76.	76.	76.	76.	0.	0.	0.	0.	0.	0.	0.	0.	0.
7	83.	76.	72.	79.	79.	79.	79.	79.	79.	79.	79.	0.	0.	0.	0.	0.	0.	0.	0.	0.
8	86.	78.	75.	82.	82.	82.	82.	82.	82.	82.	82.	0.	0.	0.	0.	0.	0.	0.	0.	0.
9	89.	81.	78.	86.	86.	86.	86.	86.	86.	86.	86.	0.	0.	0.	0.	0.	0.	0.	0.	0.
10	94.	85.	83.	91.	91.	91.	91.	91.	91.	91.	91.	0.	0.	0.	0.	0.	0.	0.	0.	0.
11	120.	107.	109.	120.	120.	120.	120.	120.	120.	120.	120.	0.	0.	0.	0.	0.	0.	0.	0.	0.
12	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
13	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
14	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
15	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
17	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
18	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
19	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
20	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

WEIGHT TABLES

VEHICLE TYPE / VALUE	1	2	3	4	5	6	7	8	9	10	11	12
1	3000.	3000.	12000.	12000.	15000.	21000.	15000.	15000.	15000.	21000.	21000.	0.
2	3000.	6500.	16000.	16900.	19800.	23000.	19800.	19800.	19800.	23000.	23000.	0.
3	0.	7300.	17600.	16500.	21300.	25000.	21300.	21300.	21300.	25000.	25000.	0.
4	0.	8000.	19200.	19400.	22700.	26000.	22700.	22700.	22700.	26000.	26000.	0.
5	0.	8700.	20900.	20000.	24000.	27000.	24000.	24000.	24000.	27000.	27000.	0.

Figure 9. BRIGLD1 Output for I-495 and U.S. 1 (Continued)

6	0.	9800.	22600.	20200.	25800.	29500.	25800.	25800.	25800.	29500.	29500.	0.
7	0.	10000.	25050.	21500.	28500.	34700.	28500.	28500.	28500.	34700.	34700.	0.
8	0.	10400.	27500.	22400.	32000.	45200.	32000.	32000.	32000.	45200.	45200.	0.
9	0.	11000.	29750.	23400.	34400.	52000.	34400.	34400.	34400.	52000.	52000.	0.
10	0.	11800.	32000.	24800.	36700.	56800.	36700.	36700.	36700.	56800.	56800.	0.
11	0.	12500.	33250.	26800.	38900.	60000.	38900.	38900.	38900.	60000.	60000.	0.
12	0.	13400.	34500.	29300.	41700.	62700.	41700.	41700.	41700.	62700.	62700.	0.
13	0.	14500.	35300.	30800.	44600.	65000.	44600.	44600.	44600.	65000.	65000.	0.
14	0.	16000.	36100.	31600.	47100.	66300.	47100.	47100.	47100.	66300.	66300.	0.
15	0.	17800.	37050.	32300.	48800.	67300.	48800.	48800.	48800.	67300.	67300.	0.
16	0.	18800.	38000.	33300.	52600.	68200.	52600.	52600.	52600.	68200.	68200.	0.
17	0.	19800.	39550.	34100.	55000.	69700.	55000.	55000.	55000.	69700.	69700.	0.
18	0.	20800.	41100.	35300.	57000.	70200.	57000.	57000.	57000.	70200.	70200.	0.
19	0.	21300.	46650.	37000.	58800.	71000.	58800.	58800.	58800.	71000.	71000.	0.
20	0.	22600.	52200.	39600.	61000.	71500.	61000.	61000.	61000.	71500.	71500.	0.
21	0.	25000.	55150.	59700.	65900.	83900.	65900.	65900.	65900.	83900.	83900.	0.
22	0.	0.	58100.	0.	0.	0.	0.	0.	0.	0.	0.	0.
23	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
24	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
25	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
26	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
27	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
28	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
29	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
30	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

TRAFFIC DISTRIBUTION

VEHICLE TYPE / DIRECTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.830	0.894	0.927	0.942	0.968	1.000	0.906	0.919	0.953	0.988	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	0.830	0.875	0.885	0.888	0.891	0.894	0.906	0.919	0.953	0.988	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

TRUCK PLATOON DISTRIBUTION

NUMBER OF TRUCKS / DIRECTION	1	2	3	4	5	6	7	8	9	10
1	1.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	1.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SIMULATION START AT 14.0 SECONDS, END AT START + 18000.0 SECONDS

Figure 9. BRIGLD1 Output for I-495 and U.S. 1 (Continued)

TOTAL VEHICLES GENERATED = 603 SIMULATED TIME = 18000. SECONDS

PLATOON DISTRIBUTION

	1	2	3	4	5	6	7	8	9	10
GENERATED FORWARD	103	0	0	0	0	0	0	0	0	0
SAMPLED ON BRIDGE	101	1	0	0	0	0	0	0	0	0

TYPE DISTRIBUTION

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
500	39	21	9	14	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LOAD DISTRIBUTION

0. TO 8000.	5
8000. TO 16000.	23
16000. TO 24000.	28
24000. TO 32000.	12
32000. TO 40000.	11
40000. TO 48000.	7
48000. TO 56000.	6
56000. TO 64000.	2
64000. TO 72000.	9
72000. TO 80000.	0
80000. TO 88000.	0
88000. TO 96000.	0
ABOVE 96000.	0

Figure 9. BRIGLD1 Output for I-495 and U.S. 1 (Continued)

The results from the stress program did not appear as favorable in this case, when compared to field collected data per Table 27, as did the other simple span cases. Two significiant factors enter into the evaluation of the comparison of real stress range data and synthesized data which can cause variances between these data, i.e.,

1. The content of the simulated truck traffic, the weights of the trucks, their speeds and the size of the sample as compared to the real truck traffic that occurred in the generation of the real stress range data.

2. The theoretical specification of the structural characteristics of the bridge as compared to its actual structural characteristics.

While the stress range data, as shown in Table 27, does not distribute over the range of stresses collected in the field it is contained within the ranges collected in the field. The synthetic results are heavily skewed toward the lower stress ranges. This tendency could be caused by one of two, or both, factors i.e.,

1. The generated truck traffic from BRIGLD1 was composed of lighter trucks on the whole than the real sample contained.

2. The specified structural properties in the input data to BRGSTRS was weighted toward a stiffer response than was true of the real bridge.

Partial output of this case is shown in Figure 10.

TABLE 27. Comparison of Measured and Predicted Incidence of Bridge Stress Maxima (I-495 and U.S. 1)

Stress Range	0 - 200	200-400	400-600	600-800	800-1000	1000-1200	1200-1400	1400-1600	1600-1800	1800-2000	above 2000
Measured (%) (673 Trucks)	-	2.25	12.25	14.25	18.75	10.4	9.9	8.0	4.5	3.05	16.65
Predicted (%) (103 Trucks)	-	40.0	51.4	8.6	-	-	-	-	-	-	-

```
MD I-495 AND U.S. 1 - SIMPLE SPAN - 5TH SPAN

INPUT TAPE NO.   7    OUTPUT TAPE NO.   0
&INPUTA
XLB=  38.000000     ,NL=            2,YBCL=  19.500000     ,EC=  4300000.0     ,ES=  30000000.     ,NUC= 0.19999999     ,NUS=
 0.29999995     ,DT= 0.49999997E-01,THRSH=  50.000000     ,WEIGHT=  115000.00     ,DR= 0.62500000     ,NJS= 0.29999995     ,CRUD=
  2.4375000     ,CRLD=  5.3750000     ,NB=            7,NSUP=            2,C2LRU= 0.0            ,C2LRL= 0.0            ,DRT=
 0.62500000     ,NLRU=            19,NLRL=            19,CLRU=  1.8125000     ,CLRL=  5.5250000     ,ILSC=            0,TL=  7.0000000     ,IL=
           1,SIGTHS=  300.00000     ,DSIG=  1000.0000     ,NDBUG=            0,            0,            0,            0,            0,
           0,            0,            0,            0,            0
&END
```

Figure 10. BRGSTRS Output for I-495 and U.S. 1

```
YCL(J)
         6.5000        19.5000

SUPPORT POSITIONS      0.0       38.00

  BEAM   NRU   NRL          IUR           ILR          YB           B   NCS   ISC   IB
   1      4     4       0.749E-02     0.749E-02       0.0         3.583    3     1     1
XCS(N,J)
     7.000       31.000      38.000
INRT,EBAR,C,E
      0.103E 05       0.300E 08      9.190        0.300E 08
INRT,EBAR,C,E
      0.103E 05       0.300E 08      9.190        0.300E 08
INRT,EBAR,C,E
      0.103E 05       0.300E 08      9.190        0.300E 08

  BEAM   NRU   NRL          IUR           ILR          YB           B   NCS   ISC   IB
   2      9     9       0.749E-02     0.749E-02      7.167        7.167    3     1     1
XCS(N,J)
     7.000       31.000      38.000
INRT,EBAR,C,E
      0.103E 05       0.300E 08      9.190        0.300E 08
INRT,EBAR,C,E
      0.103E 05       0.300E 08      9.190        0.300E 08
INRT,EBAR,C,E
      0.103E 05       0.300E 08      9.190        0.300E 08

  BEAM   NRU   NRL          IUR           ILR          YB           B   NCS   ISC   IB
   3      9     9       0.749E-02     0.749E-02     14.333        7.167    3     1     1
XCS(N,J)
     7.000       31.000      38.000
INRT,EBAR,C,E
      0.103E 05       0.300E 08      9.190        0.300E 08
INRT,EBAR,C,E
      0.103E 05       0.300E 08      9.190        0.300E 08
INRT,EBAR,C,E
      0.103E 05       0.300E 08      9.190        0.300E 08

  BEAM   NRU   NRL          IUR           ILR          YB           B   NCS   ISC   IB
   4      9     9       0.749E-02     0.749E-02     21.500        7.167    3     1     1
XCS(N,J)
     7.000       31.000      38.000
INRT,EBAR,C,E
      0.103E 05       0.300E 08      9.190        0.300E 08
INRT,EBAR,C,E
      0.103E 05       0.300E 08      9.190        0.300E 08
INRT,EBAR,C,E
      0.103E 05       0.300E 08      9.190        0.300E 08

  BEAM   NRU   NRL          IUR           ILR          YB           B   NCS   ISC   IB
   5      9     9       0.749E-02     0.749E-02     28.667        7.167    3     1     1
XCS(N,J)
     7.000       31.000      38.000
INRT,EBAR,C,E
      0.103E 05       0.300E 08      9.190        0.300E 08
INRT,EBAR,C,E
      0.103E 05       0.300E 08      9.190        0.300E 08
INRT,EBAR,C,E
      0.103E 05       0.300E 08      9.190        0.300E 08

  BEAM   NRU   NRL          IUR           ILR          YB           B   NCS   ISC   IB
```

Figure 10. BRGSTRS Output for I-495 and U.S. 1 (Continued)

```
      6      9      9       0.749E-02        0.749E-02        35.833       7.167     3     1     1
XCS(N,J)
        7.000       31.000       38.000
INRT,EBAR,C,E
          0.103E 05        0.300E 08         9.190         0.300E 08
INRT,EBAR,C,E
          0.103E 05        0.300E 08         9.190         0.300E 08
INRT,EBAR,C,E
          0.103E 05        0.300E 08         9.190         0.300E 08

   BEAM    NRU    NRL              IUR              ILR              YB             B    NCS    ISC    IB
      7      4      4       0.749E-02        0.749E-02        43.000       3.583     3     1     1
XCS(N,J)
        7.000       31.000       38.000
INRT,EBAR,C,E
          0.103E 05        0.300E 08         9.190         0.300E 08
INRT,EBAR,C,E
          0.103E 05        0.300E 08         9.190         0.300E 08
INRT,EBAR,C,E
          0.103E 05        0.300E 08         9.190         0.300E 08

          DELX             IT              ET
          9.500        0.163E 04       0.400E 07

IOPT1  IOPT2  IOPT3  IOPT4
     1      1      1      0

NPTS      POINT 1     POINT 2     POINT 3     INPUT  POINTS

    0         0.0
    0         0.0
    1        19.000
    1        19.000
    1        19.000
    0         0.0
    0         0.0

 GRID CENTERS LONGITUDINALLY - X
  0.4750E 01  0.1425E 02  0.2375E 02  0.3325E 02  0.0         0.0         0.0         0.0         0.0         0.0
  0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
  0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
  0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
  0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
  0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
  0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
  0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0

NPTS      POINT 1     POINT 2     POINT 3    CONVERTED POINTS

    0         0.0
    0         0.0
    1        23.750
    1        23.750
    1        23.750
    0         0.0
    0         0.0

IPTS
    0   0   0      0   0   0      3   0   0      3   0   0      3   0   0
```

Figure 10. BRGSTRS Output for I-495 and U.S. 1 (Continued)

STRESS EVENT 1 LOAD EVENT 1 BEAM 3 POINTS * 23.750

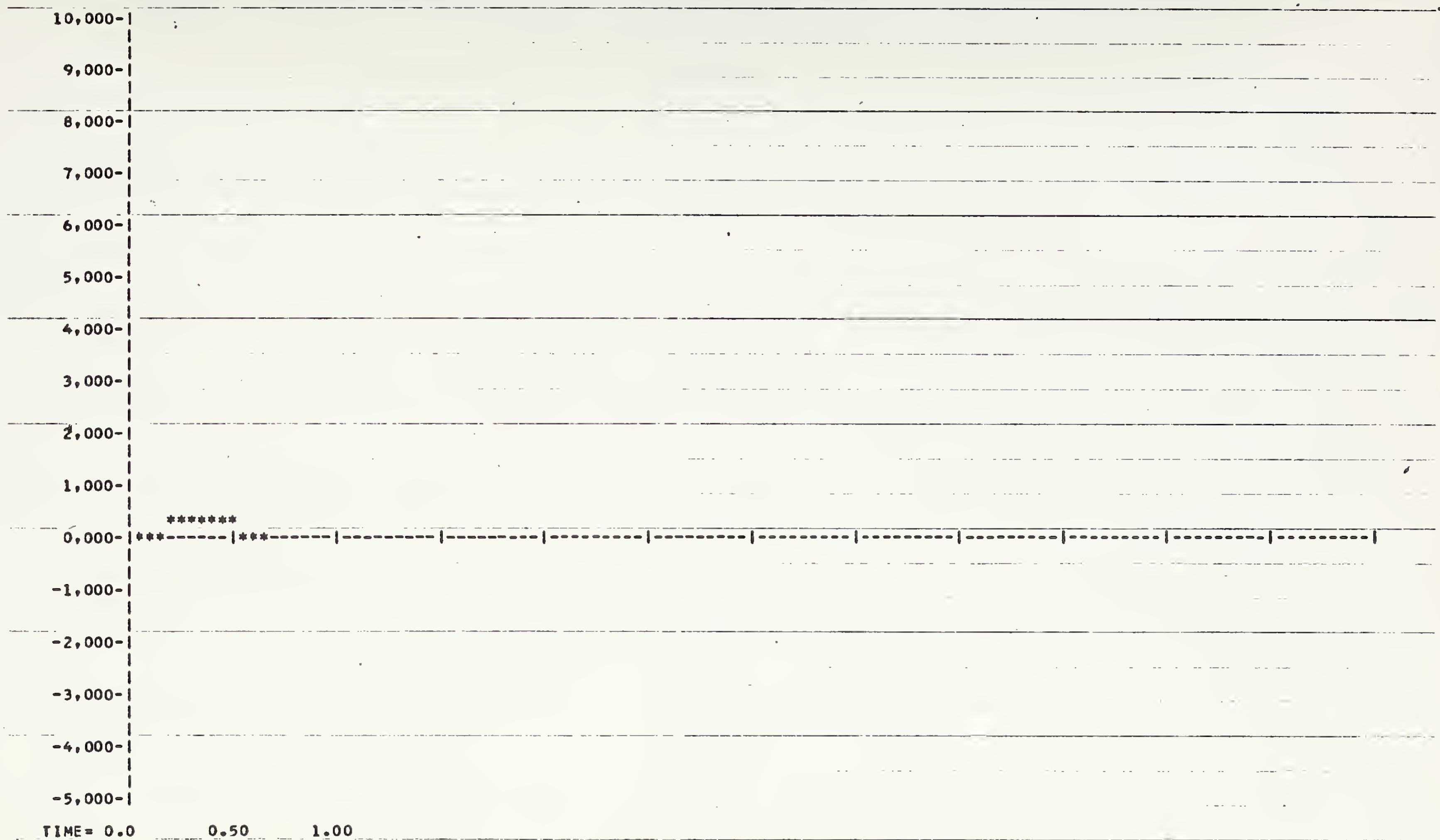


Figure 10. BRGSTRS Output for I-495 and U.S. 1 (Continued)

```
STRESS EVENT   1    LOAD EVENT   1

BEAM NO.   3    POINT    23.750

STRESSES: MINIMUM    TIME           MAXIMUM   TIME            RANGE
            16.98  0.050             422.90  0.400            405.91

BEAM NO.   4    POINT    23.750

STRESSES: MINIMUM    TIME           MAXIMUM   TIME            RANGE

BEAM NO.   5    POINT    23.750

STRESSES: MINIMUM    TIME           MAXIMUM   TIME            RANGE
```

Figure 10. BRGSTRS Output for I-495 and U.S.1 (Continued)

STRESS HISTOGRAMS

BEAM	POINT	10% INTERVALS TO 1000.0	TO 2000.0	TO 3000.0	TO 4000.0	TO 5000.0	TO 6000.0	TO 7000.0	TO 8000.0	TO 9000.0	TO 10000.0
3	23.750	33	0	0	0	0	0	0	0	0	0
4	23.750	1	1	0	0	0	0	0	0	0	0
5	23.750	1	0	0	0	0	0	0	0	0	0

Figure 10. BRGSTRS Output for I-495 and U.S. 1 (Continued)

I-83 and Bunker Hill Road

Auto traffic was assumed to be an arbitrary constant and set at 83% of the total traffic for this bridge. The truck distribution data used was based upon actual measurements taken at the bridge (3). This data only allowed for five truck types, i.e., 2D, 3, 2S1, 2S2 and 3S2. A comparison of the measured incidence of these truck types and the five hours of simulation generated by BRIGLD1 is shown in Table 28.

In this case no means of comparing total or average truck weights directly was possible from available data.

The manner in which the truck traffic appeared on the bridge deck in the simulation generated 117 load events of 117 single truck events in the five hours of simulated loading.

The real sample contained 7444 trucks in a 7 day period or one truck every 1.35 minutes. The simulated sample contained only 117 trucks in a five hour period or, again, approximately 1/2 the rate indicated by the real data. This can easily be accounted for and corrected in the BRIGLD1 input data. The headway tables require adjustment due to the lack of the high frequency data masked in the 4 hour means available from the real sample data.

The input data used to generate this loading data is shown in Figure 11, and the five hour generated data is also shown in Figure 11.

TABLE 28. Comparison of Truck Distributions for the I-83 and Bunker Hill Road Bridge

Truck Types	2D	3	2S1	2S2	3S2
Measured (%)	18.4	2.6	7.2	27.4	44.4
Simulated (%)	16.2	4.3	10.2	28.2	41.0

```
&DATA
NTH=          1,TIMLIM=  18000.000     ,DELTIM=  1.0000000     ,ND=           6,NL=           2,MD=           1,NRAND=     732158,ITOUT=
          7,BRLEN=  25.000000     ,BRPOS=  1025.0000     ,NZ=           0,SPDLIM=  95.333481     ,TRKLIM=  80.666794     ,EXSPD=
  22.000031     ,SPDMIN=  58.666763     ,ACCEL=  15.000000     ,SDFAC=  15.000000     ,SAFDIS=  10.000000     ,LT=          12,TALINC=
  8000.0000     ,DBUG=F
&END
```

Figure 11. BRIGLD1 Output for I-83 and Bunker Hill Rd.

ZONE DATA

BEGIN FORWARD UPGRADE	END FORWARD UPGRADE	BEGIN REVERSE UPGRADE	END REVERSE UPGRADE	PERCENT OF GRADE
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0

VEHICLE DATA

VEHICLE TYPE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
NUMBER OF AXLES	2	2	2	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VEHICLE POWER	150.	136.	157.	165.	184.	184.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
VEHICLE LENGTH	19.0	23.0	28.0	54.0	54.0	54.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FIRST AXLE POSITION	3.0	4.0	4.0	4.0	4.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.50	.25	.25	.20	.10	.20	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
SECOND AXLE POSITION	14.0	19.0	20.0	15.5	15.5	17.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.50	.75	.75	.50	.30	.40	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
THIRD AXLE POSITION	0.0	0.0	0.0	48.0	48.0	48.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.0	.0	.0	.30	.60	.40	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
FOURTH AXLE POSITION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
FIFTH AXLE POSITION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

Figure 11. BRIGLD1 Output for I-83 and Bunker Hill Rd. (Continued)

COEFFICIENTS OF ACCELERATION

WEIGHT/HORSEPOWER	C(0) +	C(1)V +	C(2)V**2 +	C(3)TAN(THETA)
0-50	14.70000	0.10000	0.0	140.00000
50-100	11.70000	0.09000	0.0	120.00000
100-200	13.00000	0.24700	0.00118	90.00000
200-300	9.30000	0.19800	0.00107	44.00000
300-400	5.70000	0.15000	0.00100	28.00000
OVER 400	4.00000	0.10200	0.00065	38.00000

Figure 11. BRIGLD1 Output for I-83 and Bunker Hill Rd. (Continued)

A SIMULATION TO REPRESENT A PERIOD OF 5.0 HOURS.

VEHICLES ARE GENERATED 1025. FEET FROM BRIDGE-CENTER. WEIGHTS ON BRIDGE
ARE SUMMED AND COUNTED FOR LOAD INCREMENTS OF 8000. POUNDS UP TO 88000..
1 PERIOD TYPES AND 6 VEHICLES TYPES ARE CONSIDERED.

HEADWAY TABLES

VALUE NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
DIRECTION																				
1	6.50	7.00	7.50	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00	20.50	21.00	50.00	65.00
2	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.30	1.50	1.60	1.80	2.00	2.10	2.50	2.80	3.00	3.50	4.10	5.20

VALUE NUMBER	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
DIRECTION																				
1	70.00	80.00	90.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	5.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SPEED TABLES

VEHICLE TYPE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
VALUE																				
1	40.	40.	30.	32.	32.	32.	32.	32.	32.	32.	32.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	66.	62.	56.	60.	60.	60.	60.	60.	60.	60.	60.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3	71.	66.	60.	66.	66.	66.	66.	66.	66.	66.	66.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4	74.	69.	64.	70.	70.	70.	70.	70.	70.	70.	70.	0.	0.	0.	0.	0.	0.	0.	0.	0.
5	77.	71.	67.	73.	73.	73.	73.	73.	73.	73.	73.	0.	0.	0.	0.	0.	0.	0.	0.	0.
6	80.	74.	70.	76.	76.	76.	76.	76.	76.	76.	76.	0.	0.	0.	0.	0.	0.	0.	0.	0.
7	83.	76.	72.	79.	79.	79.	79.	79.	79.	79.	79.	0.	0.	0.	0.	0.	0.	0.	0.	0.
8	86.	78.	75.	82.	82.	82.	82.	82.	82.	82.	82.	0.	0.	0.	0.	0.	0.	0.	0.	0.
9	89.	81.	78.	86.	86.	86.	86.	86.	86.	86.	86.	0.	0.	0.	0.	0.	0.	0.	0.	0.
10	94.	85.	83.	91.	91.	91.	91.	91.	91.	91.	91.	0.	0.	0.	0.	0.	0.	0.	0.	0.
11	120.	107.	109.	120.	120.	120.	120.	120.	120.	120.	120.	0.	0.	0.	0.	0.	0.	0.	0.	0.
12	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
13	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
14	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
15	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
17	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
18	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
19	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
20	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

WEIGHT TABLES

VEHICLE TYPE	1	2	3	4	5	6	7	8	9	10	11	12
VALUE												
1	3000.	3000.	12000.	12000.	15000.	21000.	15000.	15000.	15000.	21000.	21000.	0.
2	3000.	6500.	16000.	16900.	19800.	23000.	19800.	19800.	19800.	23000.	23000.	0.
3	0.	7300.	17600.	18500.	21300.	25000.	21300.	21300.	21300.	25000.	25000.	0.
4	0.	8000.	19200.	19400.	22700.	26000.	22700.	22700.	22700.	26000.	26000.	0.
5	0.	8700.	20900.	20000.	24000.	27000.	24000.	24000.	24000.	27000.	27000.	0.

Figure 11. BRIGLD1 Output for I-83 and Bunker Hill Rd. (Continued)

6	0.	9800.	22600.	20200.	25800.	29500.	25800.	25800.	25800.	29500.	29500.	0.
7	0.	10000.	25050.	21500.	28500.	34700.	28500.	28500.	28500.	34700.	34700.	0.
8	0.	10400.	27500.	22400.	32000.	45200.	32000.	32000.	32000.	45200.	45200.	0.
9	0.	11000.	29750.	23400.	34400.	52000.	34400.	34400.	34400.	52000.	52000.	0.
10	0.	11800.	32000.	24800.	36700.	56800.	36700.	36700.	36700.	56800.	56800.	0.
11	0.	12500.	33250.	26800.	38900.	60000.	38900.	38900.	38900.	60000.	60000.	0.
12	0.	13400.	34500.	29300.	41700.	62700.	41700.	41700.	41700.	62700.	62700.	0.
13	0.	14500.	35300.	30800.	44600.	65000.	44600.	44600.	44600.	65000.	65000.	0.
14	0.	16000.	36100.	31600.	47100.	66300.	47100.	47100.	47100.	66300.	66300.	0.
15	0.	17800.	37050.	32300.	48800.	67300.	48800.	48800.	48800.	67300.	67300.	0.
16	0.	18800.	38000.	33300.	52600.	68200.	52600.	52600.	52600.	68200.	68200.	0.
17	0.	19800.	39550.	34100.	55000.	69700.	55000.	55000.	55000.	69700.	69700.	0.
18	0.	20800.	41100.	35300.	57000.	70200.	57000.	57000.	57000.	70200.	70200.	0.
19	0.	21300.	46650.	37000.	58800.	71000.	58800.	58800.	58800.	71000.	71000.	0.
20	0.	22600.	52200.	39600.	61000.	71500.	61000.	61000.	61000.	71500.	71500.	0.
21	0.	25000.	55150.	59700.	65900.	83900.	65900.	65900.	65900.	83900.	83900.	0.
22	0.	0.	58100.	0.	0.	0.	0.	0.	0.	0.	0.	0.
23	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
24	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
25	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
26	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
27	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
28	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
29	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
30	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

TRAFFIC DISTRIBUTION

VEHICLE TYPE / DIRECTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.830	0.861	0.866	0.878	0.924	1.000	0.906	0.919	0.953	0.988	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	0.830	0.875	0.885	0.888	0.891	0.894	0.906	0.919	0.953	0.988	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

TRUCK PLATOON DISTRIBUTION

NUMBER OF TRUCKS / DIRECTION	1	2	3	4	5	6	7	8	9	10
1	1.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	1.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SIMULATION START AT 14.0 SECONDS, END AT START + 18000.0 SECONDS

Figure 11. BRIGLD1 Output for I-83 and Bunker Hill Rd. (Continued)

TOTAL VEHICLES GENERATED = 706 SIMULATED TIME = 18000. SECONDS

PLATOON DISTRIBUTION

	1	2	3	4	5	6	7	8	9	10
GENERATED FORWARD :	117	0	0	0	0	0	0	0	0	0
SAMPLED ON BRIDGE	117	0	0	0	0	0	0	0	0	0

TYPE DISTRIBUTION

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
588	19	5	12	33	48	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LOAD DISTRIBUTION

0. TO 8000.	0
8000. TO 16000.	15
16000. TO 24000.	22
24000. TO 32000.	19
32000. TO 40000.	14
40000. TO 48000.	6
48000. TO 56000.	9
56000. TO 64000.	18
64000. TO 72000.	11
72000. TO 80000.	2
80000. TO 88000.	1
88000. TO 96000.	0
ABOVE 96000.	0

Figure 11. BRIGLD1 Output for I-83 and Bunker Hill Rd. (Continued)

The input data for the stress calculations is shown in Figure 12. The results produced by BRGSTRS as compared to measured field data are also shown in Figure 12. This case, of all the simple span cases, required more effort to get results than all of the other simple span cases together. Input errors caused serious problems and several reruns. Fortunately, this case only utilized eight minutes of CPU time for the five hour simulated load period, for a compression ratio of 37 to 1 of real time. This bridge was a three lane bridge with 8 beams and sampled with strain gages on beams 4 and 5. Initially, the sample point input data to BRGSTRS was established as the same as the field test. However, this generated no output from BRGSTRS. The reason for this was the manner in which the synthetic load data had been generated by BRIGLD1. There was, in this synthetic sample of truck load data, a concentration of trucks in the first lane with little truck traffic in the second lane. This caused low stresses to appear, via the coupling effect, in beams 4 and 5 of the synthesized test case. Consequently, no stress output was generated by BRGSTRS. All of the stresses were calculated and the program proceeded correctly but the selected sample points, the steady state threshold value input and the change of stress required by the control on determining stress points of maxima prevented the output of data. A sample point at midspan of beam 2 was also specified in the final run. It was selected because of its location under lane 1. The cause of the problem was anticipated but not known for certain. The midspan point was chosen for the obvious reason of having the best chance of acquiring significant stress values. The results obtained were those expected and are shown in comparison with the field collected on and off the cover plate on beams 4 and 5 in Table 29.

```
MD I-83 AT BUNKER HILL - CENTER SPAN OF 3 SPAN BRIDGE

INPUT TAPE NO.   7    OUTPUT TAPE NO.   0
&INPUTA
XLB=  47.000000   ,NL=          2,YBCL=  21.082993    ,EC=  4300000.0    ,ES=  30000000.    ,NUC= 0.19999999    ,NUS=
 0.29999995    ,DT= 0.49999997E-01,THRSH=  50.000000    ,WEIGHT=  151000.00    ,DR= 0.62500000    ,NUS= 0.29999995    ,CRUD=
 -1.9369993    ,CRLD=  5.0599995    ,NB=          8,NSUP=          2,C2LRU= 0.0          ,C2LRL= 0.0          ,DRT=
 0.62500000    ,NLRU=          10,NLRL=          10,CLRU=  1.3119993    ,CLRL=  5.6869993    ,ILSC=          0,T1=  7.0000000    ,IL=
          1,SIGTHS=  50.000000    ,DSIG=  200.00000    ,NDBUG=          0,          0,          0,          0,          0,
          0,          0,          0,          0,          0
&END
```

Figure 12. BRGSTRS Output for I-83 and Bunker Hill Rd.

```
YCL(J)
         7.0280         21.0830

SUPPORT POSITIONS      0.0      47.00

 BEAM   NRU   NRL          IUR            ILR          YB          B   NCS   ISC   IB
  1      3     3       0.749E-02      0.749E-02      0.375       3.333   3     1     1
XCS(N,J)
     12.917      33.000      47.000
INRT,EBAR,C,E
       0.602E 04     0.300E 08     10.490     0.300E 08
INRT,EBAR,C,E
       0.995E 04     0.300E 08     10.490     0.300E 08
INRT,EBAR,C,E
       0.602E 04     0.300E 08     10.490     0.300E 08

 BEAM   NRU   NRL          IUR            ILR          YB          B   NCS   ISC   IB
  2      6     6       0.749E-02      0.749E-02      6.292       5.917   3     1     1
XCS(N,J)
     12.917      33.000      47.000
INRT,EBAR,C,E
       0.602E 04     0.300E 08     10.490     0.300E 08
INRT,EBAR,C,E
       0.995E 04     0.300E 08     10.490     0.300E 08
INRT,EBAR,C,E
       0.602E 04     0.300E 08     10.490     0.300E 08

 BEAM   NRU   NRL          IUR            ILR          YB          B   NCS   ISC   IB
  3      6     6       0.749E-02      0.749E-02     12.208       5.917   3     1     1
XCS(N,J)
     12.917      33.000      47.000
INRT,EBAR,C,E
       0.602E 04     0.300E 08     10.490     0.300E 08
INRT,EBAR,C,E
       0.995E 04     0.300E 08     10.490     0.300E 08
INRT,EBAR,C,E
       0.602E 04     0.300E 08     10.490     0.300E 08

 BEAM   NRU   NRL          IUR            ILR          YB          B   NCS   ISC   IB
  4      6     6       0.749E-02      0.749E-02     18.125       5.917   3     1     1
XCS(N,J)
     12.917      33.000      47.000
INRT,EBAR,C,E
       0.602E 04     0.300E 08     10.490     0.300E 08
INRT,EBAR,C,E
       0.995E 04     0.300E 08     10.490     0.300E 08
INRT,EBAR,C,E
       0.602E 04     0.300E 08     10.490     0.300E 08

 BEAM   NRU   NRL          IUR            ILR          YB          B   NCS   ISC   IB
  5      6     6       0.749E-02      0.749E-02     24.042       5.917   3     1     1
XCS(N,J)
     12.917      33.000      47.000
INRT,EBAR,C,E
       0.602E 04     0.300E 08     10.490     0.300E 08
INRT,EBAR,C,E
       0.995E 04     0.300E 08     10.490     0.300E 08
INRT,EBAR,C,E
       0.602E 04     0.300E 08     10.490     0.300E 08

 BEAM   NRU   NRL          IUR            ILR          YB          B   NCS   ISC   IB
```

Figure 12. BRGSTRS Output for I-83 and Bunker Hill Rd. (Continued)

```
    6    6    6      0.749E-02      0.749E-02      29.958      5.917    3    1    1
XCS(N,J)
      12.917      33.000      47.000
INRT,EBAR,C,E
         0.602E 04      0.300E 08      10.490      0.300E 08
INRT,EBAR,C,E
         0.995E 04      0.300E 08      10.490      0.300E 08
INRT,EBAR,C,E
         0.602E 04      0.300E 08      10.490      0.300E 08

  BEAM   NRU   NRL              IUR              ILR            YB          B    NCS   ISC    IB
    7     6     6        0.749E-02        0.749E-02        35.875      5.917    3     1     1
XCS(N,J)
      12.917      33.000      47.000
INRT,EBAR,C,E
         0.602E 04      0.300E 08      10.490      0.300E 08
INRT,EBAR,C,E
         0.995E 04      0.300E 08      10.490      0.300E 08
INRT,EBAR,C,E
         0.602E 04      0.300E 08      10.490      0.300E 08

  BEAM   NRU   NRL              IUR              ILR            YB          B    NCS   ISC    IB
    8     3     3        0.749E-02        0.749E-02        41.790      3.333    3     1     1
XCS(N,J)
      12.917      33.000      47.000
INRT,EBAR,C,E
         0.602E 04      0.300E 08      10.490      0.300E 08
INRT,EBAR,C,E
         0.995E 04      0.300E 08      10.490      0.300E 08
INRT,EBAR,C,E
         0.602E 04      0.300E 08      10.490      0.300E 08

          DELX             IT             ET
         9.400      0.202E 04      0.400E 07

IOPT1  IOPT2  IOPT3  IOPT4
    1      1      1      0

NPTS     POINT 1     POINT 2     POINT 3     INPUT  POINTS

   0       0.0
   1      23.500
   0       0.0
   2      12.917      33.000
   2      12.917      33.000
   0       0.0
   0       0.0
   0       0.0

GRID CENTERS LONGITUDINALLY - X
 0.4700E 01  0.1410E 02  0.2350E 02  0.3290E 02  0.4230E 02  0.0   0.0   0.0   0.0   0.0
 0.0         0.0         0.0         0.0         0.0         0.0   0.0   0.0   0.0   0.0
 0.0         0.0         0.0         0.0         0.0         0.0   0.0   0.0   0.0   0.0
 0.0         0.0         0.0         0.0         0.0         0.0   0.0   0.0   0.0   0.0
 0.0         0.0         0.0         0.0         0.0         0.0   0.0   0.0   0.0   0.0
 0.0         0.0         0.0         0.0         0.0         0.0   0.0   0.0   0.0   0.0
 0.0         0.0         0.0         0.0         0.0         0.0   0.0   0.0   0.0   0.0
 0.0         0.0         0.0         0.0         0.0         0.0   0.0   0.0   0.0   0.0

NPTS     POINT 1     POINT 2     POINT 3     CONVERTED POINTS
```

Figure 12. BRGSTRS Output for I-83 and Bunker Hill Rd. (Continued)

```
0        0.0
1       23.500
0        0.0
2       14.100      32.900
2       14.100      32.900
0        0.0
0        0.0
0        0.0

IPTS
 0  0  0      3  0  0      0  0  0      2  4  0      2  4  0
 0  0  0      0  0  0      0  0  0      0  0  0      0  0  0
```

Figure 12. BRGSTRS Output for I-83 and Bunker Hill Rd. (Continued)

```
STRESS EVENT   1     LOAD EVENT   2

BEAM NO.   2     POINT     23.500

STRESSES: MINIMUM   TIME          MAXIMUM   TIME          RANGE
             53.44  0.050         1573.97  0.450        1520.52
            853.12  0.700         1143.99  0.750         290.87
            853.14  0.800         1153.36  0.850         300.22
             11.86  1.250          385.75  1.750         373.89

BEAM NO.   4     POINT     14.100

STRESSES: MINIMUM   TIME          MAXIMUM   TIME          RANGE

BEAM NO.   4     POINT     32.900

STRESSES: MINIMUM   TIME          MAXIMUM   TIME          RANGE

BEAM NO.   5     POINT     14.100

STRESSES: MINIMUM   TIME          MAXIMUM   TIME          RANGE

BEAM NO.   5     POINT     32.900

STRESSES: MINIMUM   TIME          MAXIMUM   TIME          RANGE
```

Figure 12. BRGSTRS Output for I-83 and Bunker Hill Rd. (Continued)

STRESS EVENT 1 LOAD EVENT 2 BEAM 2 POINTS * 23.500

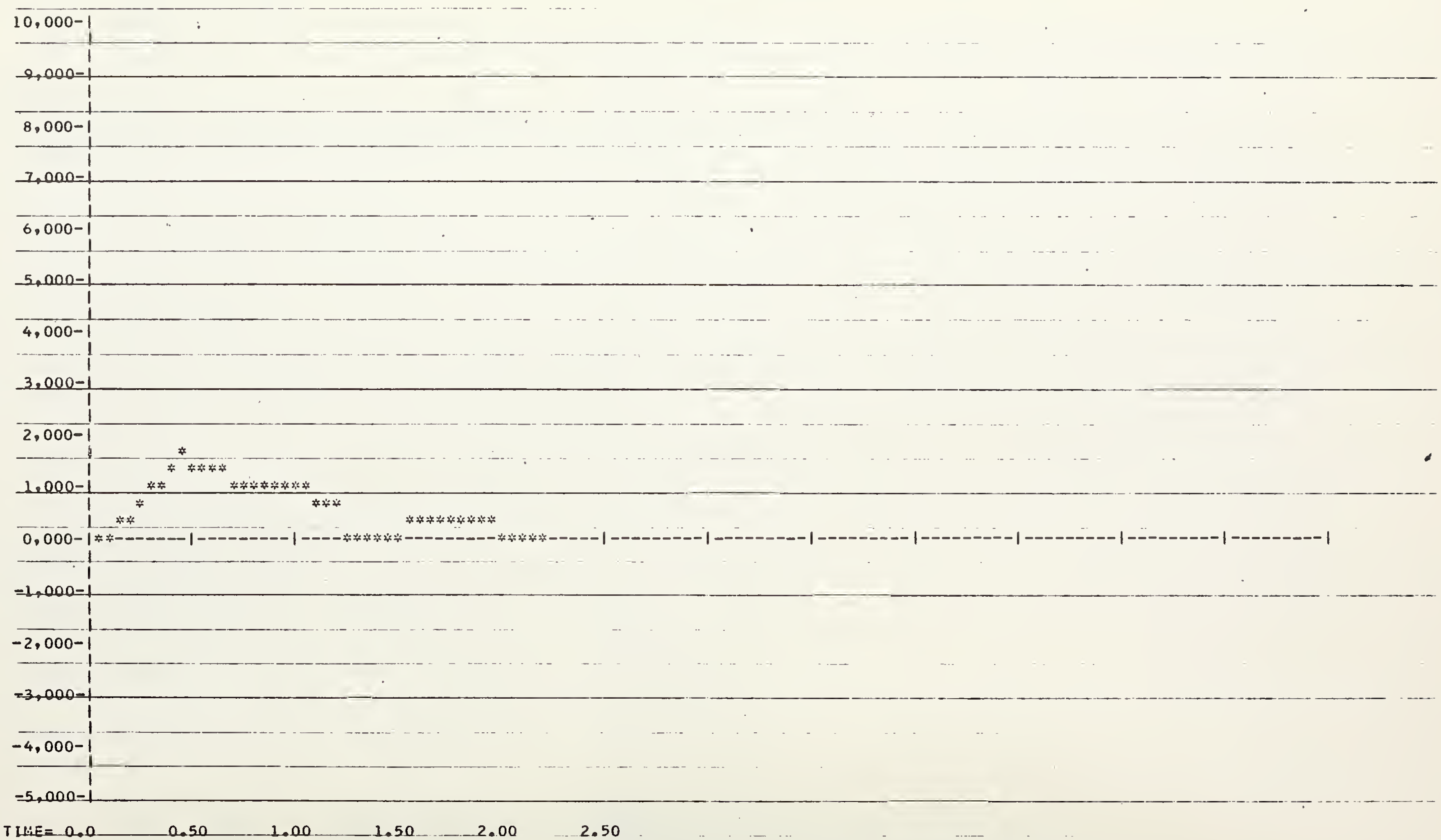


Figure 12. BRGSTRS Output for I-83 and Bunker Hill Rd. (Continued)

STRESS HISTOGRAMS

10% INTERVALS TO		200.0 TO	400.0 TO	600.0 TO	800.0 TO	1000.0 TO	1200.0 TO	1400.0 TO	1600.0 TO	1800.0 TO	2000.0
BEAM	POINT										
2	23.500	0	19	49	35	37	30	23	22	8	4
4	14.100	1	0	0	0	0	0	0	0	0	0
4	32.900	1	0	0	0	0	0	0	0	0	0
5	14.100	1	0	0	0	0	0	0	0	0	0
5	32.900	1	0	0	0	0	0	0	0	0	0

Figure 12. BRGSTRS Output for I-83 and Bunker Hill Rd. (Continued)

TABLE 29. Comparison of Measured and Predicted Stress Maxima (I-83 and Bunker Hill Rd.)

Stress (PSI)	0 - 200	200-400	400-600	600-800	800-1000	1000-1200	1200-1400	1400-1600	1600-1800	1800-2000	2000-∞
Measured (On the Cover Plate Ends)	10.0%	61.0%	26.0%	2.0%	-	-	-	-	-	-	-
Predicted (Midspan)	1.7%	8.2%	21.2%	15.2%	16.0%	13.0%	10.0%	9.5%	3.5%	1.7%	-
Measured (Off the Cover Plate Ends)	-	7.6%	24.2%	29.4%	18.0%	10.5%	3.3%	3.4%	1.7%	1.7%	-

While the synthetic sample point on beam 2 was on the cover plate, it was also subjected to higher loadings, due to the tendency of truck traffic to travel in the right most lane, than the real data reflected for beams 4 and 5 on the cover plate. Further, the real sample points on beams 4 and 5 were at the ends of the cover plate and not at midspan. A more valid comparison perhaps would have been to set the synthetic sample points as they were for beams 4 and 5, at the ends of the cover plate on beam 2. Additional variation possibly occurs because of weight per truck variances between the synthetic sample generated and the real set of trucks causing the collected set of stress range data.

In general, the results of the synthesis measured at mid span of bean 2 are essentially bracketed, as seen in Table 29, by the collected data on and off the cover plate on beams 4 and 5 and compare favorably.

Dumfries Bridge

Auto traffic density was considered as an arbitrary constant and set at 80% of the total traffic, leaving the truck traffic at 20% of the total. The truck distribution was based upon actual measurements taken on the bridge (5). This data only allowed for 4 truck types, i.e., 2, 2S1, 2S2, and 3S2. A comparison of the measured incidence of these truck types and the five hours of simulation generated by BRIGLD1 is shown in Table 30.

TABLE 30. Comparison of Truck Distributions for the Dumfries Bridge

Truck Types	2	2S1	2S2	3S2
Measured (%)	19.9	14.0	29.7	36.4
Simulated (%)	23.35	14.2	26.9	35.5

In this case, data was available to allow a comparison of the truck weights which caused the stress ranges of the real sample with the truck weights generated by BRIGLD1 for use in predicting the synthetic stress ranges. Table 31 presents a comparison of these truck weights.

The real data also provided a measure of truck weights on 1119 trucks over this bridge for a total weight of 38,306,200 pounds. The average truck weight for this sample was 34,232 pounds per truck. The average simulated truck weight was 42,538 pounds per truck. The loading of the synthetic bridge was, then, approximately 8372 pounds per truck heavier than this particular real sample indicated for the actual bridge.

The manner in which the truck traffic appeared on the bridge deck in the simulation generated 196 load events of 195 single truck events and one two truck platoon, in the five hours of simulated loading.

The annual weighing data over a two year period indicates an hourly mean truck rate of 67.18. The simulated data only provided for 39.4 trucks per hour, or approxiamtely only 60% of the real rate. The headway data utilized for this case was estimated from the given gross annual rates. However, correction of the headway tables to adjust for this variance can be easily accomplished. Similarly, the variance in weight per truck can be adjusted in the weight distribution input tables. However, the weight variance would merely tend toward the conservative. The rate correction would be far more important, in terms of the objective of these computer programs.

The input data used to generate this loading is shown in Figure 13, and the five hour generated data is shown in Figure 13.

TABLE 31. Comparison of Measured and Predicted Truck Weights (I-95 Dumfries, Virginia)

Weight Range	0 - 10000	10000 - 20000	20000 - 30000	30000 - 40000	40000 - 50000	50000 - 60000	60000 - 70000	70000 - 80000
Measured (%) (859 Trucks)	7.0	15.0	26.2	14.9	13.2	9.0	8.3	5.4
Weight Range	0 - 8000	8000 - 16000	16000 - 32000	32000 - 40000	40000 - 48000	48000 - 64000	64000 - 72000	72000 - 88000
Predicted (%) (197 Trucks)	0.0	1.0	29.9	21.3	4.0	23.9	14.7	1.5

```
&DATA
NTH=            1,TIMLIM=  18000.000    ,DELTIM=  1.0000000    ,MD=             5,NL=           2,ND=            1,NRAND=       49352,IOUT=
         7,BRLEN=  37.500000     ,BRPOS=  1037.5000     ,NZ=            0,SPDLIM=  95.333481     ,TRKLIM=  80.666794     ,EXSPD=
  22.000031     ,SPDMIN=  58.666763     ,ACCEL=  15.000000     ,SDFAC=  15.000000     ,SAFDIS=  10.000000     ,LT=          12,TALINC=
  8000.0000     ,DBUG=F
&END
```

Figure 13. BRIGLD1 Output for I-495 Dumfries, Virginia

ZONE DATA

BEGIN FORWARD UPGRADE	END FORWARD UPGRADE	BEGIN REVERSE UPGRADE	END REVERSE UPGRADE	PERCENT OF GRADE
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0

VEHICLE DATA

VEHICLE TYPE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
NUMBER OF AXLES	2	2	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VEHICLE POWER	150.	157.	165.	184.	184.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
VEHICLE LENGTH	19.0	28.0	54.0	54.0	54.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FIRST AXLE POSITION	3.0	4.0	4.0	4.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.50	.25	.20	.10	.20	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
SECOND AXLE POSITION	14.0	20.0	15.5	15.5	17.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.50	.75	.50	.30	.40	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
THIRD AXLE POSITION	0.0	0.0	48.0	48.0	48.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.0	.0	.30	.60	.40	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
FOURTH AXLE POSITION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
FIFTH AXLE POSITION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PERCENT WEIGHT ON AXLE	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

Figure 13. BRIGLD1 Output for I-495 Dumfries, Virginia (Continued)

COEFFICIENTS OF ACCELERATION

WEIGHT/HORSEPOWER	C(0) +	C(1)V +	C(2)V**2 +	C(3)TAN(THETA)
0-50	14.70000	0.10000	0.0	140.00000
50-100	11.70000	0.09000	0.0	120.00000
100-200	13.00000	0.24700	0.00118	90.00000
200-300	9.30000	0.19800	0.00107	44.00000
300-400	5.70000	0.15000	0.00100	28.00000
OVER 400	4.00000	0.10200	0.00065	38.00000

Figure 13. BRIGLD1 Output for I-495 Dumfries, Virginia (Continued)

A SIMULATION TO REPRESENT A PERIOD OF 5.0 HOURS.

VEHICLES ARE GENERATED 1038. FEET FROM BRIDGE-CENTER. WEIGHTS ON BRIDGE ARE SUMMED AND COUNTED FOR LOAD INCREMENTS OF 8000. POUNDS UP TO 88000..
1 PERIOD TYPES AND 5 VEHICLES TYPES ARE CONSIDERED.

HEADWAY TABLES

VALUE NUMBER / DIRECTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.40	5.00	7.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	17.00	21.00	27.00	37.00	60.00	90.00	3.00	3.50	4.10	5.20
2	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.30	1.50	1.60	1.80	2.00	2.10	2.50	2.80	3.00	3.50	4.10	5.20

VALUE NUMBER / DIRECTION	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	5.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	5.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SPEED TABLES

VEHICLE TYPE / VALUE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	40.	30.	32.	32.	32.	32.	32.	32.	32.	32.	32.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	66.	56.	60.	60.	60.	60.	60.	60.	60.	60.	60.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3	71.	60.	66.	66.	66.	66.	66.	66.	66.	66.	66.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4	74.	64.	70.	70.	70.	70.	70.	70.	70.	70.	70.	0.	0.	0.	0.	0.	0.	0.	0.	0.
5	77.	67.	73.	73.	73.	73.	73.	73.	73.	73.	73.	0.	0.	0.	0.	0.	0.	0.	0.	0.
6	80.	70.	76.	76.	76.	76.	76.	76.	76.	76.	76.	0.	0.	0.	0.	0.	0.	0.	0.	0.
7	83.	72.	79.	79.	79.	79.	79.	79.	79.	79.	79.	0.	0.	0.	0.	0.	0.	0.	0.	0.
8	86.	75.	82.	82.	82.	82.	82.	82.	82.	82.	82.	0.	0.	0.	0.	0.	0.	0.	0.	0.
9	89.	78.	86.	86.	86.	86.	86.	86.	86.	86.	86.	0.	0.	0.	0.	0.	0.	0.	0.	0.
10	94.	83.	91.	91.	91.	91.	91.	91.	91.	91.	91.	0.	0.	0.	0.	0.	0.	0.	0.	0.
11	120.	109.	120.	120.	120.	120.	120.	120.	120.	120.	120.	0.	0.	0.	0.	0.	0.	0.	0.	0.
12	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
13	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
14	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
15	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
17	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
18	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
19	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
20	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

WEIGHT TABLES

VEHICLE TYPE / VALUE	1	2	3	4	5	6	7	8	9	10	11	12
1	3000.	12000.	12000.	15000.	21000.	12000.	15000.	15000.	15000.	21000.	21000.	0.
2	3000.	16000.	16900.	19800.	23000.	16900.	19800.	19800.	19800.	23000.	23000.	0.
3	0.	17600.	18500.	21300.	25000.	18500.	21300.	21300.	21300.	25000.	25000.	0.
4	0.	19200.	19400.	22700.	26000.	19400.	22700.	22700.	22700.	26000.	26000.	0.
5	0.	20900.	20000.	24000.	27000.	20000.	24000.	24000.	24000.	27000.	27000.	0.

Figure 13. BRIGLD1 Output for I-495 Dumfries, Virginia (Continued)

6	0.	22600.	20200.	25800.	29500.	20200.	25800.	25800.	25800.	29500.	29500.	0.
7	0.	25050.	21500.	28500.	34700.	21500.	28500.	28500.	28500.	34700.	34700.	0.
8	0.	27500.	22400.	32000.	45200.	22400.	32000.	32000.	32000.	45200.	45200.	0.
9	0.	29750.	23400.	34400.	52000.	23400.	34400.	34400.	34400.	52000.	52000.	0.
10	0.	32000.	24800.	36700.	56800.	24800.	36700.	36700.	36700.	56800.	56800.	0.
11	0.	33250.	26800.	38900.	60000.	26800.	38900.	38900.	38900.	60000.	60000.	0.
12	0.	34500.	29300.	41700.	62700.	29300.	41700.	41700.	41700.	62700.	62700.	0.
13	0.	35300.	30800.	44600.	65000.	30800.	44600.	44600.	44600.	65000.	65000.	0.
14	0.	36100.	31600.	47100.	66300.	31600.	47100.	47100.	47100.	66300.	66300.	0.
15	0.	37050.	32300.	48800.	67300.	32300.	48800.	48800.	48800.	67300.	67300.	0.
16	0.	38000.	33300.	52600.	68200.	33300.	52600.	52600.	52600.	68200.	68200.	0.
17	0.	39550.	34100.	55000.	69700.	34100.	55000.	55000.	55000.	69700.	69700.	0.
18	0.	41100.	35300.	57000.	70200.	35300.	57000.	57000.	57000.	70200.	70200.	0.
19	0.	46650.	37000.	58800.	71000.	37000.	58800.	58800.	58800.	71000.	71000.	0.
20	0.	52200.	39600.	61000.	71500.	39600.	61000.	61000.	61000.	71500.	71500.	0.
21	0.	55150.	59700.	65900.	83900.	59700.	65900.	65900.	65900.	83900.	83900.	0.
22	0.	58100.	58100.	0.	0.	0.	0.	0.	0.	0.	0.	0.
23	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
24	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
25	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
26	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
27	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
28	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
29	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
30	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

TRAFFIC DISTRIBUTION

VEHICLE TYPE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
DIRECTION																				
1	0.800	0.840	0.868	0.927	1.000	0.894	0.906	0.919	0.953	0.988	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	0.830	0.875	0.885	0.888	0.891	0.894	0.906	0.919	0.953	0.988	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

TRUCK PLATOON DISTRIBUTION

NUMBER OF TRUCKS	1	2	3	4	5	6	7	8	9	10
DIRECTION										
1	1.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	1.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SIMULATION START AT 15.0 SECONDS, END AT START + 18000.0 SECONDS

Figure 13. BRIGLD1 Output for I-495 Dumfries, Virginia (Continued)

TOTAL VEHICLES GENERATED = 929 SIMULATED TIME = 18000. SECONDS

PLATOON DISTRIBUTION

	1	2	3	4	5	6	7	8	9	10
GENERATED FORWARD :	197	0	0	0	0	0	0	0	0	0
SAMPLED ON BRIDGE	195	1	0	0	0	0	0	0	0	0

TYPE DISTRIBUTION

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
731	46	28	53	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LOAD DISTRIBUTION

0. TO 8000.	0
8000. TO 16000.	2
16000. TO 24000.	33
24000. TO 32000.	29
32000. TO 40000.	42
40000. TO 48000.	12
48000. TO 56000.	23
56000. TO 64000.	24
64000. TO 72000.	29
72000. TO 80000.	2
80000. TO 88000.	1
88000. TO 96000.	0
ABOVE 96000.	0

Figure 13. BRIGLD1 Output for I-495 Dumfires, Virginia (Continued)

The gross results of the stress maxima generated by BRGSTRS, from the five hour simulated traffic sample, are shown in Table 32. The total incidence of maxima over .41 to approximately 1.2 KIPS is 82.8% for the real sample, which compares to 78.4% for the simulated sample. The distribution within this interval to the .4 to .8 and .8 to 1.2 intervals varies by 10% in both intervals.

The results shown in Table 32 indicate a lower stress maxima in the simulated data than in the real data. This is contrary to the previously mentioned tendency of the simulated trucks being an average of 8000 pounds per truck heavier than that shown in the real data. The values used for the effective beam moments of inertia in BRGSTRS appear to have been about 10% to high which would cause a stiffer bridge and reflect lower stress values for the same or heavier loads.

At the midspan point on beams 2 and 3, there was a total of 436 incidents for beam 2 and 102 for beam 3. The ranges on these two beams, as compared to the field measured data are shown in Table 33. The stress ranges with the greatest intensity, on beam 2, i.e., between .41 and 1.65, vary approximately from 2% to 4%. The lower end, 0. to .4, does not correlate well and relates to the cut off threshold stress value used, and possibly too stiff a bridge used in the simulation. This incidence variance roughly equals the variance on the higher end of the stress ranges between the real and predicted occurrences, which further evidences a stiffer bridge in the simulation. Beam 3 did not correlate well between the simulated and reat data. This could be due to either or both of two factors, i.e.,

1. An insufficient traffic sample and traffic rate in the 2nd lane in the simulation than were encountered in the real sample.

TABLE 32. Comparison of Measured and Predicted Incidence of Bridge Stress Maxima (I-95 Dumfries, Virginia)

Stress (KIPS)	0. - .41	.41- .84	.84- 1.24	1.24- 1.65	1.65- 2.07	2.07- 2.49	2.49- 2.88
Measured (34,448 Samples)	0%	49.6%	33.4%	10.2%	5.3%	1.4%	0.20%
Stress (KIPS)	0. - .4	.4 - .8	.8 - 1.2	1.2 - 1.6	1.6 - 2.0	2.0 - 2.4	2.4 < ∞
Predicted (700 Samples)	11.0%	59.0%	19.4%	8.1%	2.3%	0.0%	0.0%

TABLE 33. Comparison of Measured and Predicted Incidence of Bridge Stress Maxima on Beams 2 and 3 (I-95 Dumfries, Virginia)

Stress (KIPS)	0. / .41	.41 / .84	.84 / 1.24	1.24 / 1.65	1.65 / 2.07	2.07 / 2.49	2.49 / 2.88	2.88
Measured Beam 2	0.%	43.7%	31.1%	10.9%	10.6%	3.2%	0.4%	0.0%
Measured Beam 3	0.%	40.4%	33.3%	16.0%	7.9%	1.9%	0.3%	0.0%
Stress (KIPS)	0. / .4	.4 / .8	.8 / 1.2	1.2 / 1.6	1.6 / 2.0	2.0 / 2.4	2.4 / 2.8	2.8
Predicted Beam 2	8.0%	48.2%	27.1%	13.1%	3.7%	0.0%	0.0%	0.0%
Predicted Beam 3	17.6%	81.4%	1.0%	0.0%	0.0%	0.0%	0.0%	0.0%

2. Too stiff a coupling effect in the lateral direction used in BRGSTRS.

In evaluating these results, it should be kept in mind that the real sample represented 34,448 stress range occurrences, while the simulated sample only represented 700 stress range occurrences. In order to simulate an equivalent amount of incidents, it would require approximately one half hour of computer time to simulate the traffic and thirty hours of computer time to calculate the stresses.

One additional note on this case is that it utilized 36 minutes of CPU time in the "go" step for a compression ratio of 8.3 to 1 of real time.

Figure 14 presents samples of the output from BRGSTRS on this case.

```
SIMPLE STEEL SPAN - DUMFRIES VA. BRIDGE I-95

INPUT TAPE NO.   7    OUTPUT TAPE NO.   0
&INPUTA
XL8=  74.500000    ,VL=            2,YBCL=  20.833328    ,FC=  4300000.0    ,ES=  30000000.    ,NUC= 0.19999999    ,NUS=
 0.29999995    ,OT= 0.49999997E-01,THRSH=  50.000000    ,WEIGHT=  360000.00    ,DR= 0.62500000    ,NUS= 0.29999995    ,CRUD=
  1.0000000    ,CRLO=  7.0000000    ,NB=            5,VSUP=            2,C2LRU= 0.0            ,C2LRL= 0.0            ,ORT=
 0.62500000    ,NLRU=            4,NLRL=            8,CLRU=  1.3119993    ,CLRL=  6.6869993    ,ILSC=            0,TI=  8.0000000    ,IL=
           1,SIGTHS=  300.00000    ,OSIG=  500.00000    ,NDBUG=            0,            0,            0,            0,            0,
           0,            0,            0,            0,            0
&END
```

Figure 14. BRGSTRS Output for I-495 Dumfries, Virginia

```
YCL(J)
          6.9444         20.8333

SUPPORT POSITIONS      0.0      74.50

  BEAM   NRU   NRL          IUR            ILR           YB          B   NCS   ISC   IB
    1     4     9      0.749E-02      0.749E-02         0.0        4.167   3     1     1
XCS(N,J)
     12.250      62.250      74.500
INRT,EBAR,C,E
        0.269E 05      0.300E 08      26.000       0.300E 08
INRT,EBAR,C,E
        0.338E 05      0.300E 08      26.000       0.300E 08
INRT,EBAR,C,E
        0.269E 05      0.300E 08      26.000       0.300E 08

  BEAM   NRU   NRL          IUR            ILR           YB          B   NCS   ISC   IB
    2     9    18      0.749E-02      0.749E-02        8.333       8.333   3     1     1
XCS(N,J)
     15.000      59.500      74.500
INRT,EBAR,C,E
        0.269E 05      0.300E 08      26.000       0.300E 08
INRT,EBAR,C,E
        0.338E 05      0.300E 08      26.000       0.300E 08
INRT,EBAR,C,E
        0.269E 05      0.300E 08      26.000       0.300E 08

  BEAM   NRU   NRL          IUR            ILR           YB          B   NCS   ISC   IB
    3     9    18      0.749E-02      0.749E-02       16.667       8.333   3     1     1
XCS(N,J)
     15.000      59.500      74.500
INRT,EBAR,C,E
        0.269E 05      0.300E 08      26.000       0.300E 08
INRT,EBAR,C,E
        0.338E 05      0.300E 08      26.000       0.300E 08
INRT,EBAR,C,E
        0.269E 05      0.300E 08      26.000       0.300E 08

  BEAM   NRU   NRL          IUR            ILR           YB          B   NCS   ISC   IB
    4     9    18      0.749E-02      0.749E-02       25.000       0.333   3     1     1
XCS(N,J)
     15.000      59.500      74.500
INRT,EBAR,C,E
        0.269E 05      0.300E 08      26.000       0.300E 08
INRT,EBAR,C,E
        0.338E 05      0.300E 08      26.000       0.300E 08
INRT,EBAR,C,E
        0.269E 05      0.300E 08      26.000       0.300E 08

  BEAM   NRU   NRL          IUR            ILR           YB          B   NCS   ISC   IB
    5     9    18      0.749E-02      0.749E-02       33.333       0.333   3     1     1
XCS(N,J)
     15.000      59.500      74.500
INRT,EBAR,C,E
        0.269E 05      0.300E 08      26.000       0.300E 08
INRT,EBAR,C,E
        0.338E 05      0.300E 08      26.000       0.300E 08
INRT,EBAR,C,E
        0.269E 05      0.300E 08      26.000       0.300E 08

  BEAM   NRU   NRL          IUR            ILR           YB          B   NCS   ISC   IB
```

Figure 14. BRGSTRS Output for I-495 Dumfries, Virginia (Continued)

```
      6      4      9        0.749E-02        0.749E-02        41.667        4.167     3     1     1
   XCS(N,J)
      12.250        62.250        74.500
   INRT,EBAR,C,E
        0.269E 05        0.300E 08        26.000        0.300E 08
   INRT,EBAR,C,E
        0.338E 05        0.300E 08        26.000        0.300E 08
   INRT,EBAR,C,E
        0.269E 05        0.300E 08        26.000        0.300E 08

         DELX             IT             ET
        9.313        0.525E 04        0.450E 07

   IOPT1  IOPT2  IOPT3  IOPT4
      1      1      1      0

   NPTS      POINT 1      POINT 2      POINT 3      INPUT  POINTS


      0         0.0
      2        15.000        37.500
      2        15.000        37.500
      2        15.000        37.500
      2        15.000        37.500
      0         0.0

    GRID CENTERS LONGITUDINALLY - X
     0.4656E 01  0.1397E 02  0.2328E 02  0.3259E 02  0.4191E 02  0.5122E 02  0.6053E 02  0.6984E 02  0.0         0.0
     0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
     0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
     0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
     0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
     0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
     0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0
     0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0         0.0

   NPTS      POINT 1      POINT 2      POINT 3      CONVERTED POINTS


      0         0.0
      2        13.969        41.906
      2        13.969        41.906
      2        13.969        41.906
      2        13.969        41.906
      0         0.0

   IPTS
      0   0   0        2   5   0        2   5   0        2   5   0        2   5   0
      0   0   0        0   0   0        0   0   0        0   0   0        0   0   0
```

Figure 14. BRGSTRS Output for I-495 Dumfries, Virginia (Continued)

STRESS EVENT 1 LOAD EVENT 4 BEAM 2 POINTS * 13.969 + 41.906

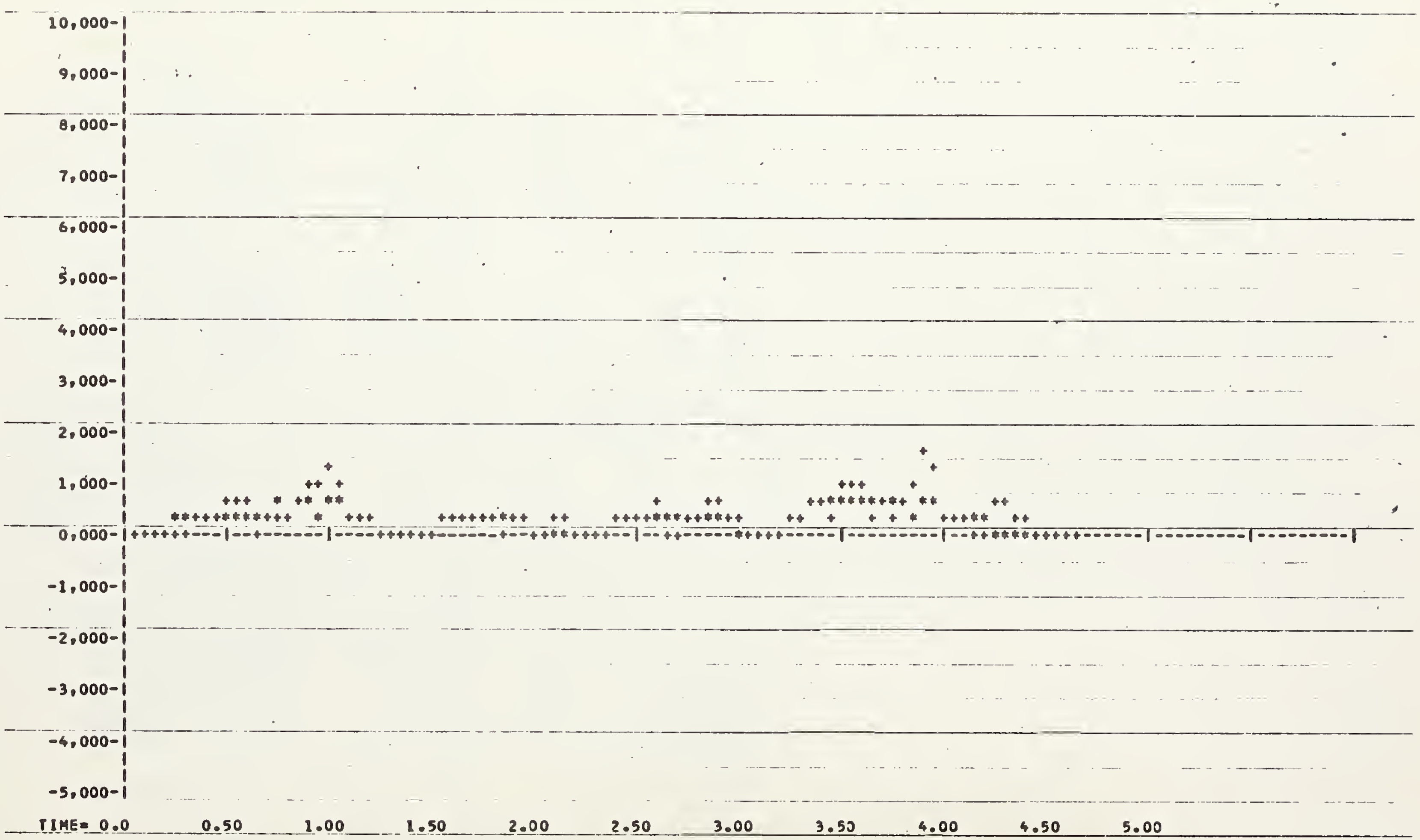


Figure 14. BRGSTRS Output for I-495 Dumfries, Virginia (Continued)

STRESS EVENT 1 LOAD EVENT 4 BEAM 3 POINTS * 13.969 + 41.905

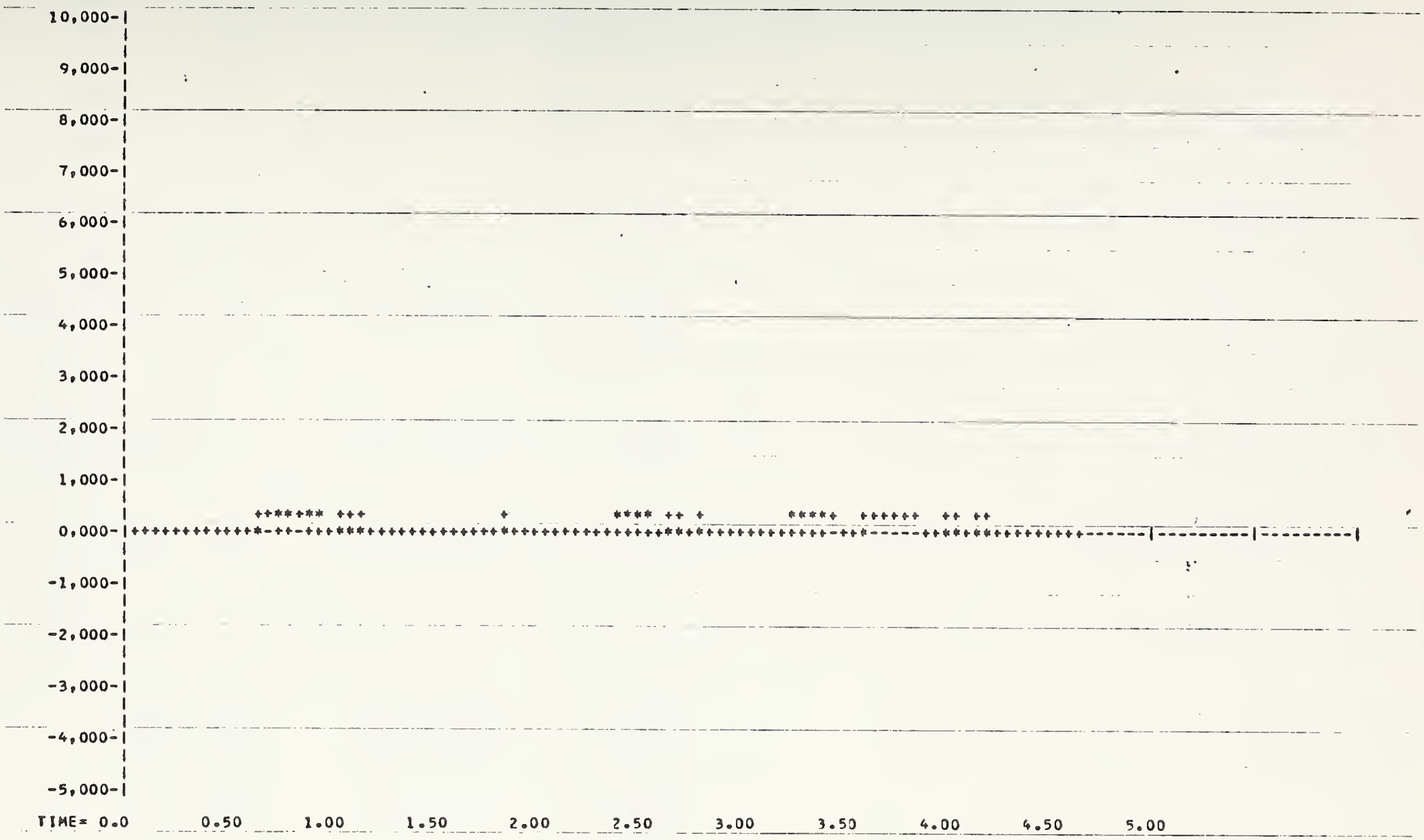


Figure 14. BRGSTRS Output for I-495 Dumfries, Virginia (Continued)

```
STRESS EVENT   1    LOAD EVENT   4

BEAM NO.   2     POINT     13.969

STRESSES: MINIMUM    TIME              MAXIMUM   TIME            RANGE
            21.76   0.050               631.80   1.000           610.05
            17.71   1.250               577.89   3.900           560.18

BEAM NO.   2     POINT     41.906

STRESSES: MINIMUM    TIME              MAXIMUM   TIME            RANGE
             5.89   0.050               532.57   0.550           526.68
           110.58   0.650              1329.88   1.000          1219.29
             4.79   1.250               418.75   1.800           413.96
            13.54   2.050               337.79   2.100           324.25
             8.22   2.250               589.21   2.600           580.99
            79.97   2.650               714.11   2.900           634.14
            13.42   3.050               968.76   3.550           955.34
           276.01   3.650              1584.73   3.900          1308.72
           -77.19   4.200               644.00   4.250           721.18

BEAM NO.   3     POINT     13.969

STRESSES: MINIMUM    TIME              MAXIMUM   TIME            RANGE

BEAM NO.   3     POINT     41.906

STRESSES: MINIMUM    TIME              MAXIMUM   TIME            RANGE
             1.63   0.050               393.18   1.100           391.56
             1.31   1.250               401.47   4.000           400.16

BEAM NO.   4     POINT     13.969

STRESSES: MINIMUM    TIME              MAXIMUM   TIME            RANGE

BEAM NO.   4     POINT     41.906

STRESSES: MINIMUM    TIME              MAXIMUM   TIME            RANGE

BEAM NO.   5     POINT     13.969

STRESSES: MINIMUM    TIME              MAXIMUM   TIME            RANGE

BEAM NO.   5     POINT     41.906

STRESSES: MINIMUM    TIME              MAXIMUM   TIME            RANGE
```

Figure 14. BRGSTRS Output for I-495 Dumfries, Virginia (Continued)

STRESS HISTOGRAMS

10% INTERVALS TO		500.0 TO	1000.0 TO	1500.0 TO	2000.0 TO	2500.0 TO	3000.0 TO	3500.0 TO	4000.0 TO	4500.0 TO	5000.0
BEAM	POINT										
2	13.969	35	94	2	0	0	0	0	0	0	0
2	41.906	80	247	73	36	0	0	0	0	0	0
3	13.969	15	2	0	0	0	0	0	0	0	0
3	41.906	89	16	1	0	0	0	0	0	0	0
4	13.969	1	2	0	0	0	0	0	0	0	0
4	41.906	3	2	1	0	0	0	0	0	0	0
5	13.969	0	0	0	0	0	0	0	0	0	0
5	41.906	0	0	0	0	0	0	0	0	0	0

Figure 14. BRGSTRS Output for I-495 Dumfries, Virginia (Continued)

Overall Results

The results of the analysis of the four simple span cases indicates that both BRIGLD1 and BRGSTRS can be used to predict stress range occurrences with at least ball park accuracy. However, the results of the four initial attempts to predict stress range occurrences can not be used as the sole measure of the validity or accuracy of these programs. As was indicated earlier, the cases presented could be easily improved by especially rerunning BRIGLD1 with better headway data to improve the generated truck rate. Further, the input data to BRGSTRS, representing the structural characteristics of each bridge, could be further refined to improve the correlation of each bridge's structural characteristics. No attempt was made to improve the input data, which should be the normal procedure when performing design analysis.

One significant output of this set of cases was some insight into the computer running time of the dynamic stress analysis program BRGSTRS. The original test case used during the development of the program utilized truck load data generated by BRIGLD1, which in turn, used the erroneous U.S. 301 (Md.) data that caused traffic densities to be exceedingly high and unrealistic. This test case implied a 1 to 1 relationship of computer time to real time. However, the cases run in this effort varied, for the simple span cases, from 6 to 1 up to 37 to 1. The utilization of computer time by BRGSTRS is a direct function of truck traffic density.

Another significant output of the work performed on these test cases was the determination of the extremely slow soltuion of stresses for continuous beam cases by BRGSTRS and the need to improve this situation. Such improvement should be made before practical and frequent use of the program is made on continuous beam bridges.

A limitation exists on the use of this approach due to available disk storage on the computer being used. The number of loads generated by SYNGEN is only limited by the disk storage available for use in HISGEN to store each single axle stress time curve, generated by BRGSTRS. Each curve is allowed to have up to 100 time points. A maximum of 30 sample points, 3 per each of a maximum of 10 beams, is established in BRGSTRS. It is anticipated that a nominal maximum case would exist for

1. Eleven axle weights
2. Six speeds
3. Two lanes
4. Thirty sample points

This requires approximately 4000 records of 100 words or 400 bytes of disc storage availability for use by HISGEN to utilize single axle stress traces generated by BRGSTRS from the single axle loads generated by SYNGEN.

Similarly, the number of truck stress time traces generated by the subroutine TRKTRC in HISGEN is limited by the available disc storage on which to store the truck traces. It is anticipated in this instance that a nominal maximum case would exist for

1. Six truck types
2. Ten speeds
3. Two lanes
4. Thirty sample points

In this case each truck stress trace is allowed to have up to 200 time points. This requires approximately 3600 records of 200 words each or 800 bytes each. Hqwever, the program, HISGEN, does allow up to twenty different truck types to be specified. This would increase the required disk storage to 12,000 records of 200 words each.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations presented here will be of four forms; i.e.,

1. General Comments

2. Identified deficiencies in the existing programs which require resolution and the recommended resolution.

3. Identified limitations in the existing programs which require extension or generalization and the recommended action.

4. Major considerations in the research and development of the techniques for attacking the long-term fatique problem and recommendations of actions.

5. Other avenues that should be investigated.

However, the discussion of the above categories will first be within the context of each program followed by a general discussion. The programs are:

1. The BRIGLD1 Simulator

2. The Structural Analysis Program (BRGSTRS)

3. The Stress Signature System, which is made up of

    (1) The Synthetic Load Generator (SYNGEN),

    (2) The Structural Analysis Program (BRGSTRS), and

    (3) The Histogram Program (HISGEN).

General Comments

There is an inherent flexibility in the programs which compose the two systems defined in Figures 1 and 2. The keystone program is BRGSTRS. It can interface with

1. Arbitrary bridge load sources, provided the data is in a compatible format, on the input side,

2. Arbitrary analytical programs on the output side,

or

3. Provide a limited analytical output of its own as the ending program.

This capability lends itself to the research and investigation of other forms for generating bridge loads and predicting long term stress ranges.

In addition to theoretical use, data from other sources, configured in the proper format such as field data, may be input to BRGSTRS and HISGEN, e.g.,

1. In the case of BRGSTRS real truck data collected on-site, weight, speed and lane, from a controlled experiment or actual data can be substituted for the synthetic data generated by BRIGLD1 or SYNGEN on magnetic tape.

2. In the case of HISGEN real stress data, reduced from collected strain gage data, correlated with truck data, can be used as input, in the proper format, to HISGEN as a substitute for the output of BRGSTRS.

In using BRIGLD1 and BRGSTRS, care should be taken in the development of all input data. In the case of BRIGLD1, truck statistics should be carefully generated and a simulation performed and analyzed before processing the load data on BRGSTRS. If the results, generated truck statistics, do not

agree well enough with known data, then, the input data should be modified and the case rerun on BRIGLD1, prior to using BRGSTRS. BRIGLD1 is substantially more economical to utilize than BRGSTRS and will be the basic source of variance between real and simulated stress data. Providing sufficiently accurate truck load data from BRIGLD1 will minimize reruns on the long running BRGSTRS program.

In the event the direct input data for BRIGLD1 is not available, estimates can be used initially and varied until the desired truck statistics are generated by the program, at which time BRGSTRS may be used.

The BRIGLD1 simulator

The identified deficiencies in the BRIGLD1 simulator are:

1. Inadequate weight-horsepower influence in the simulation.

2. Lack of influence of downgrades in the simulation.

3. Lack of influence of the passing restriction in the simulation.

4. In bidirectional traffic flow, crashes occur.

5. Simulation algorithm converges to zero or specified minimum speed.

6. Degradation of the preservation of prescribed traffic statistics over long simulation time periods.

In the case of the weight-horsepower effect, a better representation could be included with a small effort.

The downgrade and passing restriction does not appear to work in the simulation. This would require thorough checking of the coding and modification of the validity of this conclusion. Correcting it will be of a minor nature.

The bidirectional flow simulation appears to have problems. Inadvertent "crashes" occur which are due to an inadequate representation of two-way traffic. This requires detailed analysis of the coding to determine the cause and a small effort to correct the problem.

Far more significant is the tendency of the algorithm to converge on zero speed. It should oscillate about the steady state speed. Logical or mathematical errors, or an inadequate representation, apparently are the cause of this problem. This would require a moderate effort to investigate. However, it might not be correctable except by a complete replacement of the motion simulation algorithm.

Another extremely significant apparent deficiency is the simulator's tendency to fail in the preservation of the prescribed traffic statistics over long simulation periods. The implication, as indicated earlier, is that the pseudo-random number generator is being used improperly for the necessary functions.

Correction of this is straightforward and of a minor nature. However, there is an uncertainty that such a correction will eliminate the problem and adequate testing after such a correction would be necessary.

The identified limitations in the BRIGLD1 Simulator are:

1. Limited to two lanes of traffic, and

2. Limited to initial generating of traffic in the right lane only.

In order to provide more than two lanes of traffic simulation, a moderate effort is required. Substantial rework of logic, data handling and buffering, and motion synthesis would be required. It is recommended that if such an extension is attempted, a complete replacement of the traffic simulation algorithm be made, which would also correct all deficiencies and limitations.

The restriction to one-lane generation is nonsensical and should be replaced. A different basis of generation would be required but the effort required would be small in nature.

Perhaps the most significant conclusion is the basic ineptness ponderousness and economic infeasibility of the approach for handling the long-term fatigue problem upon which the BRIGLD1 simulator is based. Further, the non-rigorousness of the approach places a large uncertainty upon the value of any fatigue generated by this technique because the load content, trucks, is uncontrollable. This is regardless of the validity and accuracy of the empirical data fed into the simulator. Also, the above defined remaining deficiencies in the simulator, even after the significant effort expended in correcting and improving it, cause a great deal of doubt about the value of its generated load data.

In order to analyze one bridge for a 100-year life span, let's assume a 2-week simulation period, which will be representative

of each 5-year interval in the 100 years. This amounts to 6,720 hours of real time. At a compression of 720 to one, for the simulator alone, this requires 9.3 hours of computer time. Each two-week sample could be multiplied by 130, i.e., for each stress maxima occurrence, to represent a five-year period. The best estimate at present on the stress analysis calculational time indicates at best about a 37 to 1 compression on time. This implies the need for a total of about 234 hours of computer time, which is not a practical approach.

The only solution to this problem is to use a very simplified stress analysis calculation, which will compress real time on the order of the simulator. This would still require approximately 20 hours of computer time.

It is concluded that the concept of simulating traffic to generate time dependent load data and the subsequent generation of dynamic stress, for the prediction of stress maxima, in turn for predicting long-term fatigue is not practical and has a large uncertainty regarding the proper representation of truck platoon events, their configuration and most importantly their weight.

The Dynamic Structural Analysis Program

This program is of a utilitarian nature to the overall problem of predicting long-term stress maxima histograms for fatigue analysis. It was not developed in the sense of advancing the state-of-the-art.

If the traffic simulation approach is utilized to generate load events, an extremely simplified method will need to be implemented as a replacement for this program.

In general, it is felt that the program developed is adequate for the purpose it is to serve. However, it requires improvements from a utility point of view, but these should be established after some significant use of the program has been made.

While substantial testing of this program was performed and several production type runs were made with it which provided very good comparisons with field collected data, it is felt that substantial further testing, or very careful production use, is still required to determine its limitations and deficiencies.

A serious deficiency exists in BRGSTR in the calculation of stresses for multiple span continuous beams. Because of the restriction on core memory, it was not feasible to calculate all of the flexibility matrices and their modified inverses for each span and save them for use during the entire run. Consequently they are currently being calculated for each time point which causes excessive use of computer time. So much so that it is not recommended that the program be used for more than a few load events, at present, on continuous beam cases. This problem, i.e., use of large amounts of computer time on continuous beam problems, can be minimized by initially generating these matrices, as is done for the simple span case, saving them in temporary disk files during the run and retrieving them from disk at each time point for use.

At present, the following suggestions are made concerning this problem:

1. Analysis of the effects of varying Δt on a highly responsive bridge should be performed.

2. Comparison of dynamic stresses for specific loads on a given bridge should be made against real data to provide a basis for measuring its accuracy in predicting stresses. Comparative testing performed in this study was limited to stress range incidence of random truck traffic.

The Stress Signature Program System

The analytical technique developed in this investigation, based upon the idea of single axle stress signatures for any given bridge, is certainly a more efficient and more rigorous approach toward predicting long-term fatigue of bridges than the traffic simulation approach. However, insufficient testing and evaluation of this approach does not allow any valid conclusions to be drawn.

Continued improvement and extension of the model and the computer program is also required before a viable tool will be forthcoming. Computer time requirements for this approach are quite small when compared to the simulation approach.

Particular limitations of the HISGEN program relate to the truck weight distributions, by type, platoon distributions and platoon configuration definitions and distributions. The primary deficiency lies in the lack of data to provide realistic choices of these values. The truck weight distribution approach was to use a maximum for each type which would always provide conservative stress range estimates. This is a practical approach but does not tend toward the concept of optimum bridge design. Platoon distribution data is literally nonexistent and this creates a definite problem in the use of HISGEN. Two techniques can be used to develop basic data, i.e.,

1. The collection and analysis of actual field data, or

2. The use of a good validated traffic simulation program and analysis of its output.

3. Extension of the discontinuity moment contribution due to a live load on one span to generating the resultant dynamic stresses on the adjacent unloaded spans of a continuous beam type bridge should be made.

4. Other forms of beams, not presently synthesized in BRGSTRS, should be included. This can be accomplished by replacing or providing an alternative option switch to the subroutine MODULI. It is this subroutine which characterizes a beam or diaphram.

5. Extending the number of lanes appears to be essential. Of the comparative tests run using real data, only one was a bridge with two lanes. All others were three lanes.

6. Providing for user or automatic specification of the scaling of the stress graphical output.

7. Modifying the program to calculate the flexibility matrix and the inverse of its modified form for each span of a continuous beam type bridge only once, i.e., in the utilization block, storing them in temporary disc files, and retrieving each matrix as necessary at each time point instead of calculating them at each time point.

In general, a great deal of learning must be accomplished about using this program before significant criticism can be made. One significant feature of the program, not a deficiency, is its ability to essentially allow a user to outsmart himself. Careful selection of output options and sample points is mandatory. Careless specification can result in no stress output even though it was calculated for all elements. Conversely, a user can be overwhelmed with output by careless specification of output options, especially the debug options.

Probably the single weakest point in HISGEN, and again its due to the lack of data primarily but also due to limiting complexity, are the definitions of the platoon configurations used in the program and the establishing of their distribution by a user in the input data. To provide improvements on these two factors, the same two approaches specified above for the platoon distribution problem, are again the practical means.

This program, and SYNGEN, like the others previously discussed should be extended to more than 2 lanes. The total time nominally necessary is then approximately .75 hours. This is in comparison to the 234 hours of computer time necessary to the simulation approach previously discussed.

Merely from the pragmatic consideration of computer time, this approach warrants serious further investigation and development. Controlled field experiments and the collection of validation data and parametric data is necessary in order to evaluate this method. Also, from the rigorous point of view, it has a lot of merit. It certainly does not have the extent of uncertainties that the BRIGLDk simulator contains, or the general simulation approach.

This approach also allows the practical use of a fairly realistic dynamic structural analysis program. Whereas, the simulator approach must be constrained to use an extremely simplified stress analysis approach to significantly reduce computer requirements.

Additionally, continued research to develop such approaches is required and should be continued. It is felt that the technique developed is of an innovative or novel nature and could lead to improved insight into better approaches, as compared to the classical engineering and simulation approaches.

Nominally, about twenty minutes of computer time will be more than adequate to generate the single axle stress signatures using BRGSTRS. Twenty minutes allows the generation of axles for eleven weights for each of six speeds in each of two lanes for approximately 24 sample points, i.e., 3168 stress curves. This provides a relatively fine grid which, in turn, should provide rather good interpolative results. The histogram program will nominally require about 40 minutes for any length of bridge life span.

Other Considerations

An alternative approach to the simulation of traffic down a synthetic highway to a synthetic bridge undergoing analysis is to stochastically generate the load events at the entrance to the deck in all lanes simultaneously. A load event would be defined by the existence of a truck in the set of vehicles entering the bridge. An analytical approach can be established for implementing such a model. Further, a conceptual variation of the manner in which the dynamic stress analysis program is applied, somewhat analogous to the stress signature concept, could reduce the computer time to a few hours, as shown previously for the stress signature method. This overall approach retains a rigorous stress analysis capability, generates realistic load events without simulating traffic and would use a practical amount of computer time for long life span periods.

Summary

In general, it is recommended that continued research or analytical methods such as the Stress Signature Method, including further development of it, and stochastic load event

generation techniques which allow the use of fairly rigorous dynamic stress analysis programs, and utilize practical amounts of computer time be performed. It is also concluded that the use of highway traffic simulation techniques are economically impractical for long-term fatigue analysis and that they should be abandoned.

REFERENCES

1. "Forecasting of Heavy Loading Patterns on Highway Bridges," H. Bissell, et al, Federal Clearing House No. PB193119, Kelly Scientific Corp.

2. "Loading History Analysis of Steel Weldments in Bridge Structures," by C. F. Galambos, et al, Unpublished Paper, 1972

3. "Tabulation of 24 Hour Dynamics Strain Data on Four Simple Span Girder - Slab Bridge Structures," C. P. Heins, et al, Report No. 29, Civil Engineering Dept., University of Maryland at College Park.

4. "Tabulation of Dynamic Strain on a Three Span Continuous Bridge Structure," A. D. Sartwell, et al, Report No. 33, Civil Engineering Dept., University of Maryland at College Park

5. "Acquisition of Loading History Data on Highway Bridges," C. F. Galambos and W. L. Armstrong, Public Roads, Vol. 35, No. 8, U.S. D.O.T., Washington, D.C.

BIBLIOGRAPHY

1. "Forecasting of Heavy Loading Patterns on Highway Bridges," H. Bissell, et al, Federal Clearing House No. PB193119, Kelly Scientific Corp.

2. "The Finite Element Method," by O.C. Zienkiewicz, Y.K. Cheung, McGraw-Hill Publishing Company

3. "Theory of Plates and Shells," by Timoshenko and Woinowsky-Krieger, McGraw-Hill Book Co. 2nd edition

4. "Strength of Materials," by Timoshenko-Young, McGraw-Hill Book Co.

5. "Structural Design for Dynamic Loads," Charles H. Norris et al (M.I.T.), McGraw-Hill Book Co., 1959

6. "Mechanical Vibrations," by W.T. Thomson, Prentice Hall, Inc.

7. "Analysis of Orthotropic Folded Plates with Eccentric Stiffeners," by K.J. William and A.C. Scordelis, Report No. SESM70-2, Dept. of Civil Engineering, University of California, Berkeley

8. "Theoretical Studies of Bridge Deck Behavior," by Graham H. Powell and Ian G. Buckle, Report No. UCSESM70-7, Dept. of Civil Engineering, University of California, Berkeley

9. "Tabulation of Dynamic Strain Data on a Girder Slab Bridge Structure During Seven Continuous Days," by H.D. Sartwell, C.P. Heins, Jr., Report No. 31, Civil Engineering Dept., University of Maryland at College Park

10. "Study of Truck Weights and the Corresponding Induced Bridge Girder Stresses," by R.L. Khosa, C.P. Heins, Jr., Report No. 40, Civil Engineering Dept., University of Maryland at College Park

11. "Tabulation of Dynamic Strain Data on a Three-Span Continuous Bridge Structure," by A. D. Sartwell, C. P. Heins, Report No. 33, Civil Engineering Dept., University of Maryland at College Park

12. "Loading History of a Highway Bridge - Comparison of Stress Range Histograms" by C. F. Galambos, C. P. Heins, Public Roads, Vol. 36, No. 9, U.S. D.O.T., Washington, D.C.

13. "Acquisition of Loading History Data on Highway Bridges" by C. F. Galambos and W. L. Armstrong, Public Roads, Vol. 35, No. 8, U.S. D.O.T., Washington, D.C.

14. "A Loading History Study of Two Highway Bridges in Virginia" by Wallace T. McKeel, Jr., Charles E. Maddox, Jr., Henry L. Kinnier and Charles F. Galambos, Virginia Highway Research Council, Dept. of Highway and University of Virginia VHRC71-Rpg, 1971

15. "Fracture Toughness Testing and its Applications," ASTM NASA, Special Technical Publication No. 381, Symposium publication at 67th Annual Meeting, 1964.

16. "Tabulation of 24 Hour Dynamics Strain Data on Four Simple Span Girder-Slab Bridge Structures," C.P. Heins, Jr., et al., Report No. 29, Civil Engineering Dept., University of Maryland at College Park

17. "Prospects for Urban Transit," Federal Clearing House No. PBI93355, Charles River Associates, Inc.

18. "The Selection of Improvement Programs on Intercity Highways," Contract Report DOT-OS-A9-060, Charles River Associates, Inc.

19. "Reliability Design for Fatigue under Random Loading" by R.C. Garson, F. Moses, Case Western Reserve University, Ohio Research Study No. 14218, Aug. 1972

20. "Loading History Analysis of Steel Weldments in Bridge Structures," by C. F. Galambos, et al, unpublished, 1972

21. "Reliability Design for Fatigue Under Random Loading," by R. C. Garson, et al, Purdue Specialty Conference, 1972

GPO 873-546

FHWA
R&D